EXHIBIT 24

ENVIRONMENTAL HEALTH
& ENGINEERING, INC.

Assessment of Sources of Polychlorinated Biphenyls in the Environment in And around the City of Spokane, Washington

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I hold these opinions and conclusions to a reasonable degree of scientific certainty. If additional or new information becomes available, I reserve the right to modify, amend, or supplement this report.

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LIST OF ABBREVIATIONS AND ACRONYMS

ATSDR	Agency for Toxic Substances and Disease Registry
BAF	Biomagnification or Bioaccumulation Factor
BCF	Bioconcentration Factor
EH&E	Environmental Health & Engineering, Inc.
IARC	International Agency for Research on Cancer
ITF	Interdepartmental Task Force
IUPAC	International Union of Pure and Applied Chemists
kg	kilogram
lbs	pounds
mmHg	millimeters of mercury
mg/L	milligrams per liter
OECD	Organisation for Economic Co-operation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PCB	polychlorinated biphenyl
PCT	polychlorinated triphenyl
ppb	parts per billion
ppm	parts per million
ppq	parts per quadrillion
ppt	parts per trillion
U.K.	United Kingdom
U.S.	United States
USEPA	U.S. Environmental Protection Agency
WWTP	waste water treatment plant

1.0 EXECUTIVE SUMMARY

This report lays out an assessment of the contributions of Monsanto Chemical Company's (Monsanto)[1] polychlorinated biphenyl (PCB) products in various environmental compartments and their transport and removal mechanisms throughout the global environment. The focus of this work is assessing the likelihood that PCBs detected in the U.S. environment are attributable to Monsanto-produced PCBs and PCB-containing products. This work relied upon documentation produced by Monsanto, government entities, and peer-reviewed literature to apply a mass-balance model to estimate the likely percentage of PCBs found in the environment of the United States (U.S.), State of Washington, and City of Spokane that is attributable to Monsanto's production. With regard to Spokane, this report relies in part on the work of Lisa A. Rodenburg, Ph.D., to support the attribution of PCBs in the Spokane River and watershed.

The analysis begins by characterizing the global production and usage of PCBs by country. Published emission factors, normalized to production quantities and specific to the type of application, are applied to these data to estimate the total amount of PCBs released to the environment. The results of dynamic mass-balance models published in the scientific literature are used to characterize the releases and amounts of PCBs into various environmental compartments. Monsanto's likely contribution to the environmental burden of PCBs in the U.S. is estimated, accounting for production, usage, inadvertent PCB production (non-commercial mixtures of PCBs from select industries, such as dye manufacturing), and global cycling of PCBs. Where significant uncertainties exist regarding the potential source of PCBs (Monsanto versus non-Monsanto PCBs), parameters that favored non-Monsanto PCBs are used, thus lowering the quantity of PCBs in the U.S. environment that could be attributable to Monsanto's products.

Based on this analysis, Monsanto is likely responsible for at least 90% of the PCBs that can be found in the environment of the U.S. Applying this analysis to the State of Washington and the City Spokane and accounting for local influences, the PCB burden in these environments are estimated. In general, the national emissions data are indexed to population to estimate state-wide and local PCB burdens. Where possible, additional state and local information are applied to the population-adjusted figures to develop more site-specific estimates of Monsanto's PCBs in those environments. Such is the case with Spokane where the mass balance dynamic model results are supplemented by the findings of Lisa Rodenburg regarding the likely presence of inadvertent and non-legacy[2] PCBs in the environment.

[1] Monsanto, as used in the report, is a general reference to all entities owned or operated by Monsanto that were actively engaged in the production of PCBs.

[2] The terms legacy or commercial PCBs, as used throughout this report, refer to PCBs that have been intentionally manufactured and attributed to Monsanto and/or other PCB manufacturers.

Monsanto-generated data indicate that the State of Washington used a disproportionately higher amount of PCB-containing fluids in nominally closed applications compared to its population-adjusted PCB usage (Monsanto Chemical Company, 1968). This is important because PCBs that are not strictly confined can more easily escape to the environment and contaminate soil, sediment, and bodies of water. Therefore, the proportion of Monsanto-produced PCBs in the State of Washington is likely to be higher than the national estimate of 90%. Any proportional contribution of PCBs from global cycling and inadvertent generation is reduced as more Monsanto-produced PCBs are released to the environment. Nominally closed applications were more likely to release PCBs to the environment by way of accidental releases and spills compared to closed uses, and likely contributed to the widespread contamination of the waterways in the State of Washington. According to the Breivik dynamic mass balance model, more than two times the proportion of PCBs used for nominally closed uses are released to the environment through accidental discharges and spills compared to closed uses. Considering this, Monsanto is likely to be responsible for more than 90% of the PCBs found in the environment of the State of Washington.

Regarding the PCBs in the Spokane River, Dr. Rodenburg evaluated over 1,000 samples collected from the Spokane River environment to determine the proportion of legacy and non-legacy PCBs in the samples. Dr. Rodenburg found that legacy PCBs represented about 91% of the PCBs in the Spokane River. This is in excellent agreement with the dynamic mass balance estimate, strengthening the confidence of both estimates as they arrived at nearly the identical conclusion using two different approaches.

2.0 INTRODUCTION

The discussion below focuses on the historic production, uses, fate, and transport of polychlorinated biphenyls (PCBs) in the global environment. This work also specifies the likely contributions of PCBs released from products manufactured by or otherwise released by Monsanto through their production and use. Many assessments and reviews of PCB releases into the environment have been carried out, and this analysis incorporates many features of that previous body of work. This report specifically assesses the contribution of Monsanto-produced PCBs released in the U.S.

2.1 POLYCHLORINATED BIPHENYLS (PCBS)

PCBs are a class of 209 discrete chemical compounds, known as congeners, that contain one to ten chlorine atoms attached to a biphenyl molecule. The biphenyl molecule is created by joining two benzene rings with a covalent bond (Erickson, 1997).[3] The general structure of the chlorinated biphenyl molecule is shown below (ATSDR, 2000):

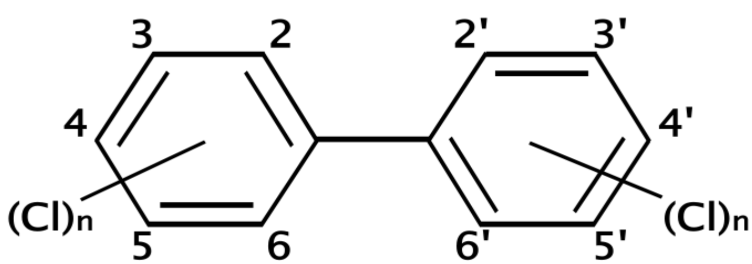

Figure 2.1 General Structure of the Chlorinated Biphenyl Molecule

The “1” position on the PCB molecule (not designated on the structure above) is the location of the carbon atom on each benzene ring that form the covalent bond, joining the two benzene molecules to create the biphenyl molecule. The remaining positions (2 through 6) are potential binding sites for chlorine atoms on the biphenyl molecule, five sites for each benzene ring. One set of numbers 2 through 6 are designated with a prime notation as a superscript to identify which benzene ring the chlorine molecule is attached when more than one chlorine atom is affixed to the biphenyl molecule.

[3] A covalent bond is formed when a pair of electrons are shared by two atoms. A benzene ring is made up of six carbon atoms and six hydrogen atoms formed into a hexagonal, ring-like structure, where the fourth carbon-carbon bond is formed by delocalized electrons. This configuration is known more generally as an aromatic structure. When two benzene rings are connected, the resulting molecule is referred to as a biphenyl molecule, which is the chemical backbone of the PCB molecule.

Each unique PCB molecule or congener may be grouped by the number of chlorine atoms it contains. Since there are a total of ten possible chlorine sites on the biphenyl ring, there are ten congener classes or isomers. Each isomer is comprised of individual congeners, ranging in number from one in the case of decachlorobiphenyl to 46 in the case of pentachlorobiphenyl. When grouped in this manner, the isomers are often referred to as "homologs" (Erickson, 1997).[4]

Each congener within a homolog group is identified by the arrangement of the chlorine atoms around the biphenyl molecule. For example, PCB-126 is 3,3',4,4',5-pentachlorobiphenyl,[5] which specifies the number and location of the chlorine atoms on the biphenyl rings. This naming convention, developed by the International Union of Pure and Applied Chemists (IUPAC), uniquely identifies each individual congener (ATSDR, 2000). This convention is highly specific and efficient for naming congeners with a small number of chlorine atoms, but it is less efficient and cumbersome to use as the number of chlorine atoms increase.

To overcome the awkwardness of the IUPAC naming convention, individual congeners are classified by number (i.e., 1 to 209) using a chemical categorization scheme proposed by Ballschmiter and Zell (known as the BZ number) and adopted by the IUPAC (IARC, 2016). In broad terms, the higher the number, the higher the degree of chlorination and molecular weight of the congener (Erickson, 1997).[6] It is the degree of chlorination and the position of the chlorine atoms that determine the chemical properties of PCBs with respect to how they mobilize and move within and between environmental media (i.e., air, water, soil, and dust) and their degradation in the environment (ATSDR, 2000; Erickson, 1997).

Although there are 209 possible PCB congeners, only about 130 of those are found in commercial mixtures.[7] Individual PCB congeners range from oily liquids to thick waxy or solid consistency with some PCBs existing as airborne vapor due to their semi-volatility (ATSDR, 2000). PCBs are lipophilic, and therefore tend to accumulate in fatty tissue in the body and in carbon-rich media in the environment (e.g., soil with a high carbon content). PCBs generally have very low solubility in water and are considered to be semi-volatile organic compounds (ATSDR, 2000; IARC, 2016).

2.2 COMMERCIAL PRODUCTION OF PCB MIXTURES

PCB mixtures were produced commercially beginning in 1929, but production significantly increased after World War II, and the uses of PCB mixtures expanded during that timeframe (refer to section 3 of this report). Most producers throughout the world reduced or stopped production in the 1970s. Monsanto was a major manufacturer, but it was not the only one. The

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[4] Erickson, 1997, p. 20, Table 2-II and p. 21, Figure 2-1.
[5] ATSDR, 2000, Table 4-2.
[6] Erickson, 1997, App A, Table A-1.
[7] Erickson, 1997, p. 33.

total worldwide production of PCBs was approximately 1,355,810 metric tons or 2,990 million pounds (lbs) of PCBs. Foreign manufacturers accounted for 53% of worldwide production, and Monsanto manufactured 47% of the global PCB production in the U.S.[8] As an organization, Monsanto manufactured over one-half (52%) of the worldwide production of PCBs, inclusive of its United Kingdom (U.K.) production quantities (IARC, 2016). Additionally, Monsanto had a business partnership with Mitsubishi in Japan. This partnership produced PCB mixtures (e.g., Santotherm) in Japan, although the total quantities of PCBs produced were relatively small on a global scale and are not included in the production estimates provided above.

From about 1935 to 1977, Monsanto was effectively the sole producer and distributer of PCB products in the U.S. (USEPA, 1976),[9] notwithstanding the vanishingly small amount of PCBs produced by Geneva Industries (De Voogt and Brinkman, 1989; Durfee, 1976; Monsanto Chemical Company, 1975a; Snyder and Fellinger, 1966).[10,11] Other companies, such as General Electric and Westinghouse, sold and marketed products that contained PCBs, such as capacitors (Durfee, 1976; Monsanto Chemical Company, 1977; Pogue, 1969; Reab, 1972; USEPA, 1976).[12,13,14] However, Monsanto was the principal and, for all practical purposes, the exclusive source of those PCBs (De Voogt and Brinkman, 1989; Durfee, 1976; Monsanto Chemical Company, 1975a; 1975c; Snyder and Fellinger, 1966; USEPA, 1976).[15,16,17,18] Although foreign-produced PCBs were imported and incorporated into products that were marketed and sold in the U.S., the PCBs in those products represented less than 1% of the total PCBs sold and used in the U.S. In 1977, due to growing concerns regarding the presence of PCBs found in the environment, Monsanto terminated the production of PCB mixtures. However, several European and Asian countries continued to produce PCB mixtures into the 1980s and, in one case until 2012 (IARC, 2016).[19]

The production of PCBs is covered in more detail in section 3.0 of this report, and the inadvertent production of PCBs is discussed in section 3.4.

[8] Calculated from IARC, 2016, Table 1.14.
[9] USEPA, 1976, p. 2.
[10] Monsanto 1975a, MONS 051311.
[11] Snyder, 1966, PCB-ARCH0293727.
[12] Monsanto, 1977, ADM 008969 -ADM 008974, ADM007166 -ADM007167, ACM 000807.
[13] Pogue 1969, MON-MT-003464.
[14] USEPA 1976, p. 69.
[15] Monsanto 1975a, MONS 051311.
[16] Monsanto 1975c, MONS 092437.
[17] USEPA, 1976, p. 2.
[18] Snyder PCB-ARCH0293727.
[19] IARC 2016, Table 1.14.

2.3 COMMERCIAL USES OF PCBS

The chemical properties of PCB products are such that they have been exploited in commercial uses. They are, among other qualities: (i) relatively insoluble in water, (ii) inflammable, (iii) good electrical insulators, and (iv) good cooling agents in lubricating fluids. Accordingly, they have been used as dielectric fluids in transformers and capacitors; as extenders and application vehicles in pesticides, adhesives, cutting oils, flame retardants, heat transfer fluids, hydraulic lubricants, sealants, and paints; and as plasticizers in carbonless copy paper (ATSDR, 2000). Purchasers of PCB products decided which Aroclor® or other PCB product to purchase depending upon the physical characteristics imparted by the PCB products and the purposes for which they would be deployed.

Most commercial applications for PCB products are generally considered to be either "closed" or "open" use. A third category, denoted as “nominally closed,” is used to describe the application of PCB products such as heat transfer or hydraulic fluids. In this special case, the PCB products are enclosed in a piping system but will inevitably leak to some extent and contaminate other surfaces in and outside of the system. Closed uses contain the PCB liquid or solid in a sealed container preventing the PCBs from having direct contact with the environment under normal operating conditions. Transformers, capacitors and light ballasts are examples of closed uses of PCB products. This type of use is allowed under the U.S. Environmental Protection Agency (USEPA) PCB regulations, provided that certain use and management stipulations are followed. Open use of PCB products allows PCBs to migrate into the outdoor environment or into other materials indoors that were not manufactured with PCBs through either direct contact or through vaporization from the source material into these other materials. Caulk, paint, and carbonless copy paper are examples of open uses of PCBs.

The most common open use of PCB products was as a plasticizer, i.e., substances providing flexibility and elongation. Carbonless copy paper represented about 28% of all Aroclor 1242 sales, used as a plasticizer (De Voogt and Brinkman, 1989; USEPA, 1976).[20,21] Caulking often contained Aroclor mixtures because of its compatibility with the base resin or binder, such as polysulfide and polybutene. According to USEPA,[22] caulking materials in use can still contain up to 44% PCBs (USEPA, 2015). Lastly, specialty paints were manufactured with Aroclor mixtures to improve durability and to provide chemical resistance to the coating (Erickson and Kaley II, 2011). In late 1970, Monsanto stopped selling Aroclors for “non-controllable end uses” (Bock et al., 1970), such as caulking and paint, but the use of existing inventories of Aroclors and stocks of product that already contained PCBs likely continued at construction sites (Erickson

[20] DeVoogt, 1989, p. 34.
[21] USEPA 1976, p. 134.
[22] https://www.epa.gov/sites/production/files/2016-03/documents/pcbs_in_building_materials_questions_and_answers.pdf.

and Kaley II, 2011) and other users stockpiled stores of PCB-containing materials prior to phase out (Papageorge, 1971).[23]

[23] Papageorge, 1971, TOWOLDMON0051180. "Sales to date slow but attributed to high inventories accumulated prior to August 30."

3.0 GLOBAL PCB PRODUCTION

Production of PCB mixtures for commercial sale and use took place in fewer than twelve countries between 1929 and as late as 2012 (Bletchly, 1983; Breivik et al., 2007; Breivik et al., 2002a; IARC, 2016). Several estimates of total global PCB production have been published in the scientific literature as well as in trade and government publications. Most global production estimates fall within the range of 2,800 to 3,000 million lbs with Monsanto U.S. accounting for almost half or 47% of the total (De Voogt and Brinkman, 1989; Durfee, 1976; IARC, 2016). In addition, manufacturing in the U.K. by Monsanto between 1954 and 1977 contributed an additional 147 million lbs or approximately 5% of this estimate (Bletchly, 1983; Breivik et al., 2007; De Voogt and Brinkman, 1989). A summary of total production by country and year is provided in Table 3.1 (reproduced from Table 1.14 of IARC, 2016).

Table 3.1 Global Polychlorinated Biphenyl Production

Producer	Country	Duration	Volume (million pounds)	Percent of Total	Reference
Monsanto	U.S.	1930 – 1977	1,414	47%	de Voogt & Brinkman, 1989
Bayer AG	West Germany	1930 – 1983	351	12%	de Voogt & Brinkman, 1989
Orgsteklo	USSR	1939 – 1990	313	10%	AMAP, 2000
Prodelec	France	1930 – 1984	297	10%	de Voogt & Brinkman, 1989
Monsanto	U.K.	1954 – 1977	147	4.9%	de Voogt & Brinkman, 1989
Kanegafuchi	Japan	1954 – 1972	124	4.2%	Tatsukawa, 1976
Orgsintez	USSR	1972 – 1993	70.6	2.4%	AMAP, 2000
Caffaro	Italy	1958 – 1983	68.6	2.3%	de Voogt & Brinkman, 1989
2.8 Vinalon and Sunchon Vinalon Complex	North Korea	1960[a] – 2012[b]	66.2[c]	2.2%	Democratic People's Republic of Korea, 2008
SA Cros	Spain	1955 – 1984	64.0	2.1%	de Voogt & Brinkman, 1989
Chemko	Czechoslovakia	1959 – 1984	47.4	1.6%	Schlosserová, 1994
Xi'an	China	1965 – 1980	22.1	0.7%	Jiang et al., 1997; People's Republic of China, 2007
Mitsubishi[d]	Japan	1969 – 1972	5.4	0.2%	Tatsukawa, 1976
Electrochemical Co.	Poland	1966 – 1970	2.2	0.07%	Sulkowski et al., 2003
Zaklady Azotowe Tarnow-Moscice	Poland	1974 – 1977	1.5	0.05%	Sulkowski et al., 2003
Geneva Industries	U.S.	1972 – 1974	1.0	0.03%	de Voogt & Brinkman, 1989
Total		1930 – 2012	2,990		

[a] During the 1960s.
[b] "The Ministry of Chemical Industry will, by 2012, take measures to dismantle the PCBs production process and establish a new process of producing an alternative."
[c] Estimated from Democratic People's Republic of Korea 2008, National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants.
[d] The Mitsubishi Monsanto Company in Tokyo produced and sold PCBs under the Aroclor and Santotherm tradenames (deVoogt and Brinkman, 1989, chapter 3, pgs. 9, 12.)

Adapted from Breivik et al., 2007, and IARC, 2016.

3.1 UNITED STATES

Numerous sources noted that Monsanto manufactured approximately 1,400 million lbs of PCBs or 99% of PCBs produced in the U.S. (USEPA, 1976) with a small contribution of 454 metric tons or approximately 1 million lbs of PCB-containing heat-transfer fluids manufactured by Geneva Industries of Houston, Texas, between 1971 and 1973 (Bletchly, 1983; De Voogt and Brinkman, 1989; Durfee, 1976). USEPA reported potential error estimates around the 1,400 million pound figure, stating that this figure could be underestimated by approximately 5% or overestimated by approximately 20% (USEPA, 1976).[24] Assuming the most conservative estimate (in terms of least estimated production attributable to Monsanto) would yield 1,120 million lbs of PCBs produced by Monsanto in the U.S. It should be noted that the estimates compiled by USEPA were based on information provided by Monsanto. Additional reporting by Monsanto from circa 1979 includes data from the USEPA report with additional production data through 1977 (Monsanto Chemical Company, Circa 1979). Data provided by Monsanto accounts for approximately 900 million lbs of PCBs produced by the company for all uses between 1960 and 1977 with production data more limited for the years prior to that time period (Monsanto Chemical Company, Circa 1979). Table 3.2 summarizes the U.S. production, imports and exports estimated by USEPA and other researchers, based primarily on data provided by Monsanto in the 1970s.

[24] USEPA 1976, p 5-8. USEPA reported at the time that estimates of total production by Monsanto in the U.S. were most uncertain for the period 1930 to 1960, when data provide by the company were limited (p. 215). According to USEPA, the use of PCBs in transformers likely traces back to the 1930s with large-scale use in capacitors related to introduction and widespread use of electrical home appliances in the mid- to late 1940s. Other applications, such as adhesives, plasticizers, lubricants, and carbon paper, likely began in the early 1950s. The extensive use of PCBs for heat transfer applications also likely began in the 1950s with production increasing dramatically into the 1970s. USEPA used three methods to estimate production by Monsanto for the period 1930 to 1975. The first used the 1960 to 1975 production rates and assumed production increased at a linear rate during 1930 to 1960. The second method employed least squares correlations to sets of Monsanto sales data between 1957 and 1974 and extrapolated back to 1930. The third method used production data compiled up to 1972 (Foster D. Snell, 1973) with additional production reports from 1973 to 1975, provided by OECD (OECD 1975).

Table 3.2 U.S. Production, Imports, and Exports of Polychlorinated Biphenyls, 1930 to 1975

Manufacturer	Years	Category	Million Pounds	% of Global Production	References
Monsanto	1930 to 1975	Production	1,100 to 1,400	37 to 47%	USEPA, 1976; Versar Inc., 1978; De Voogt, 1989
		Exports	150	5%	USEPA, 1976
		U.S. usage/sales	1,000 to 1,254	33 to 42%	USEPA, 1976
Geneva Industries	1971 to 1973	Production	1	0.03%	De Voogt, 1989
Other	1930 to 1975	Imports	3	0.1%	USEPA, 1976
		Total global production	2,990		

As shown in Figure 3.1, production of PCB-containing products hit a maximum of approximately 75 million lbs per year in 1970 with significantly reduced production subsequently, following Monsanto's voluntary ban on producing PCBs for open uses. Monsanto stopped all PCB production in 1977 before the USEPA ban was finalized in 1979 (Monsanto Chemical Company, Circa 1979).

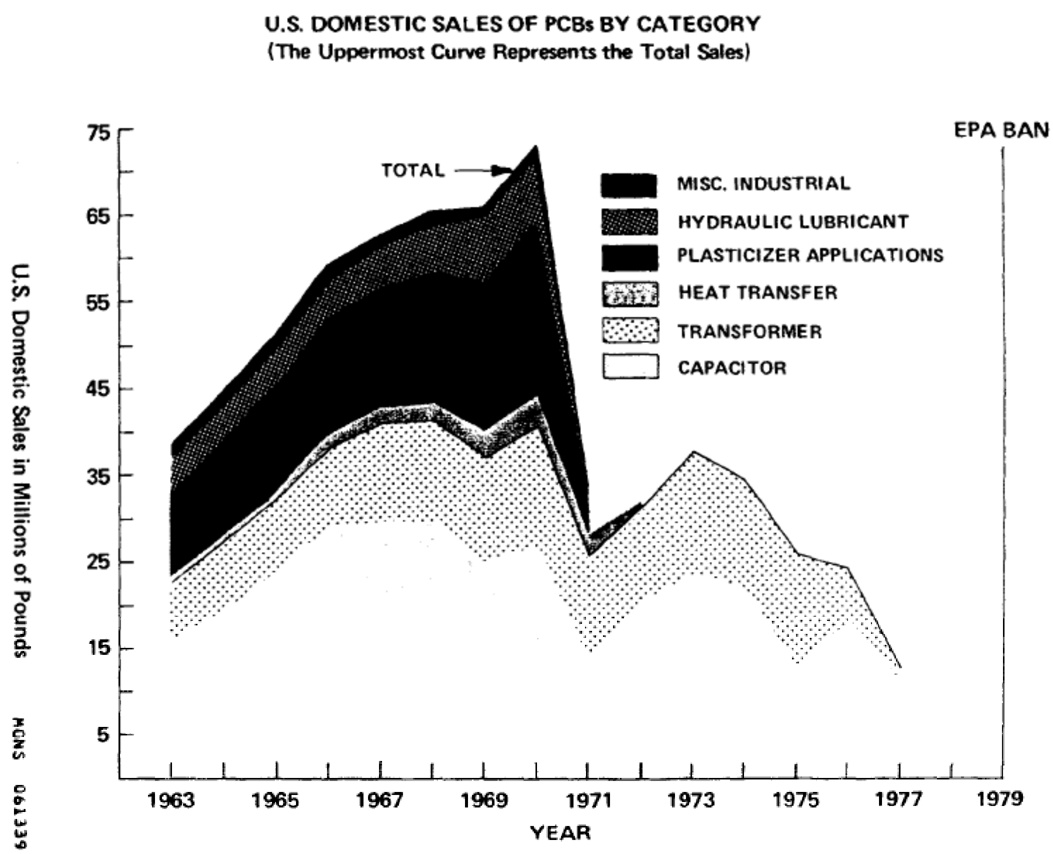

Figure 3.1 Domestic sales of PCB products produced by Monsanto in the U.S. (source: Monsanto Chemical Company, Circa 1979)

Exports of PCBs from the U.S. were reported by several sources to be within the range of 10 to 15% of U.S. production between 1963 and 1973 (Bareme, 1979; Foster D. Snell Inc., 1973) and

somewhat higher for the period 1972 to 1975 (USEPA, 1976). According to a survey conducted at the time by the Organisation for Economic Co-operation and Development (OECD), the U.S. exported Aroclors to Australia, Canada, and the U.K. (Bareme, 1979).

As of 1975, approximately 1,253 million lbs of PCBs had been produced for U.S. sales, 758 million lbs were estimated to be in service at the time; 55 million lbs had been destroyed; 290 million lbs were in landfills and dumps; and 150 million lbs released to soil, water, air, and sediment (Monsanto Chemical Company, 1975b; USEPA, 1976). As of 1975, PCBs were generally only used as a dielectric fluid in electrical transformers and capacitors, and in investment casting. Imported PCBs accounted for only 1 to 2% of domestic production by 1975. In 1973 to 1974, the primary source of PCB imports was decachlorobiphenyl from Italy for use in investment casting, accounting for 80 to 90% of all imported PCBs (Durfee, 1976; USEPA, 1976). Phenoclor imported from France comprised the remaining 10 to 20% of imports,[25] which was used in semi-enclosed heat transfer applications in the mining industry (ATSDR, 2000; Durfee, 1976; USEPA, 1976; Versar Inc., 1977).

Canada, which did not have any domestic PCB production capability, was a major importer of PCBs manufactured by Monsanto, and Monsanto was the principal source of PCB imports for Canada (Bletchly, 1983; USEPA, 1976). Between 1963 and 1970, Canada accounted for approximately half of Monsanto's exports of PCBs (Bareme, 1979). Aroclors 1016 and 1254 were the primary products purchased by Canada until PCB imports were banned in 1977 (Bareme, 1979; IARC, 2016). Estimates for the amount imported to Canada from the U.S. is 14 million lbs between 1973 and 1980 (De Voogt and Brinkman, 1989). Australia also imported Aroclor 1016 from the U.S. between at least 1973 and 1974 with little reporting available for other years (OECD, 1975; USEPA, 1976).

3.1.1 Monsanto's Aroclor® Products

Monsanto manufactured PCB mixtures in two plants located in Sauget, Illinois (Sauget Plant, a.k.a. W.G. Krummich Plant) and Anniston, Alabama (Anniston Plant) (Erickson and Kaley II, 2011). In 1929, the production of PCB mixtures began at the Anniston Plant. In 1935, when Monsanto bought Swann Chemical Company ("Swann"), Monsanto assumed the production of PCB mixtures at the Anniston Plant and expanded its operations to produce PCB mixtures at the Sauget Plant. Swann marketed several PCB mixtures under the trade name "Aroclor" (Erickson, 1997; Versar Inc., 1979).[26] Aroclor was Monsanto's trade name for its line of polychlorinated biphenyl products. Monsanto continued to sell PCB mixtures under the trade name of Aroclor and other trade names as outlined below. In 1971, the production of PCB mixtures at the

[25] USEPA, 1976, p. 141.
[26] Erickson, 1997, p. 35.

Anniston Plant was terminated (ATSDR, 2000; Versar Inc., 1979).[27] However, production continued at the Sauget Plant until August 1977 when Monsanto terminated the commercial production of PCB mixtures (ATSDR, 2000; Versar Inc., 1979).

Monsanto also operated a plant in Newport, England, that produced PCBs beginning in 1956. Monsanto sold PCBs in the U.K. for use as dielectric fluids in capacitors and transformers, among other uses. A substantial quantity of PCBs was exported to both OECD and non-OECD countries. Mirroring the product restrictions and phase-outs implemented in the U.S., Monsanto limited the production of PCBs to closed use applications only in 1970 and terminated the manufacturing of all PCBs by 1977 (Bletchly, 1983).[28]

The most widely known of the Aroclor products contained PCBs, but the product line also included Aroclors that contained polychlorinated terphenyls (PCTs), as well as mixtures and blends of PCBs and PCTs (Erickson and Kaley II, 2011).[29] The trade name Aroclor was followed by a four-digit number, in which the first two digits were "12," designating the product as a refined PCB. The second two digits specified the average percentage of chlorine, by weight, in the product. Thus, Aroclor 1242 was a PCB product containing 42% chlorine by weight (Erickson and Kaley II, 2011).[30]

For every 1200-series of Aroclors there was an 1100-series of unrefined Aroclors. In the case of PCBs, the 1100 series of Aroclors were produced during the initial step of the production process when the biphenyl molecule was chlorinated in a reactor vessel using anhydrous chlorine in the presence of a catalyst (e.g., ferric chloride). The degree of chlorination was controlled largely by the amount of time given for the reaction; generally, 12 to 36 hours. The longer the amount of time for the reaction, the higher the degree of chlorination of the biphenyl molecule (Durfee, 1976).[31] This was not a precise process and for any given reaction time it would produce a mixture of congeners with varying degrees of chlorination. In fact, the production of Aroclors was controlled using physical parameters, such as softening point or viscosity, and not the specific chemical makeup of the mixture (Durfee, 1976). In order to manufacture the 1200-series of Aroclors, the corresponding crude 1100-series material had to undergo a process of distillation to produce the desired mixture of homologs needed for a particular Aroclor commercial product based on specified physical properties for the mixture (Erickson and Kaley II, 2011).[32] Monsanto's PCB Aroclor products listed in increasing level of chlorination included: 1221, 1232, 1016, 1242, 1248, 1254, 1260, 1262 and 1268 (Erickson and Kaley II, 2011).[33]

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[27] https://www.atsdr.cdc.gov/sites/anniston_community_health_survey/overview.html.
[28] Bletchly, 1983, pp. 16-19.
[29] Erickson, 2011, p. 139.
[30] Erickson, 2011, p. 138.
[31] Durfee, 1976, p. 56.
[32] Erickson, 2011, p. 139.
[33] Erickson, 2011, p.137.

Table 3.3. summarizes the U.S. sales by commercial Aroclor mixture from 1957 to 1974. Aroclor 1242 was the predominant PCB product that was manufactured, sold, and marketed by Monsanto in the U.S. Aroclor 1242 alone accounted for one-half of the Aroclor mixtures that Monsanto manufactured and sold (Lloyd et al., 1975). This mixture represented one-third to two-thirds of the Aroclors sold in the U.S. in any given year from 1957 to 1975 (Lloyd et al., 1975). This reflects the fact that more than 70% of the Aroclors that Monsanto manufactured, marketed, and sold were used as dielectric fluids in capacitors and transformers. Aroclors 1254 and 1260 were the next most widely sold Aroclor mixtures; each Aroclor representing about 10 to 25% of the market share in any given year from 1957 to 1975 (Lloyd et al., 1975). Importantly, Aroclor 1254 was commonly used in open applications such as caulk and paint, allowing this PCB mixture to freely enter the environment.

Aroclor 1016 is a notable exception to Monsanto's naming convention for its PCB Aroclor products. The 1016 designation reflected Monsanto's system for keeping track of materials in the research stage of development (Erickson and Kaley II, 2011).[34] Each new research chemical was given a sequential "MCS" number (Monsanto Chemical Substance or Sample). MCS 1016 was the designation given to this new PCB mixture that was being developed as a suitable replacement for Aroclor 1242 in electrical equipment, and this designation (1016) became the branded commercial product. Developed and introduced after 1971, Aroclor 1016 offered a less chlorinated option compared to its counterpart Aroclor 1242, and consequently, was a preferable alternative as it was likely less persistent in the environment. Aroclor 1016 was produced by distilling Aroclor 1242 to remove the more highly chlorinated congeners, making the resulting PCB mixture potentially more biodegradable (Durfee, 1976).[35]

Table 3.3 Monsanto Production of Aroclors, 1957 to 1974

Aroclor	Years of Production	Million Pounds (%) of Monsanto U.S. Sales
1221	1957 to 1974	8 (0.9%)
1232	1957 to 1971	2 (0.3%)
1242	1957 to 1974	431 (54%)
1248	1957 to 1972	59 (7.4%)
1254	1957 to 1974	124 (16%)
1260	1957 to 1972	92 (12%)
1262	1957 to 1971	7 (0.9%)
1268	1958 to 1970	3 (0.4%)
1016	1971 to 1974	70 (8.8%)
	Total	795

Reported in Lloyd et al., 1975 and De Voogt and Brinkman, 1989.

[34] Erickson, 2011, p. 138.
[35] Durfee, 1975, p. 56.

Monsanto also produced products that were mixtures of PCB and PCT; examples include Aroclor 2565 and Aroclor 4465. Aroclor 4465 was produced by combining Aroclor 4065 with PCT (Erickson and Kaley II, 2011).[36] Aroclor 4465 was initially produced by chlorinating a mixture of biphenyl and terphenyls. In later years it was produced by blending Aroclor 5460 and Aroclor 1262. In addition, there was also a series of plasticizers formulated as blends of Aroclor 5460 and Aroclor 1221. These products were developed to allow for transition from PCB-containing plasticizers to plasticizers not containing PCBs (Erickson and Kaley II, 2011).[37] These products were the Aroclor 6000 series. In this series the final two digits indicated the amount of Aroclor 5460 in the product. An example of this is the mixture of 50% Aroclor 5460 and 50% Aroclor 1221 to comprise Aroclor 6050 (Erickson and Kaley II, 2011).[38]

3.2 EUROPE AND ASIA

The volume and duration of PCB production in foreign countries are shown in Table 3.1. Other studies have estimated worldwide production of PCBs at approximately 3,000 million lbs with half produced by Monsanto U.S. and the remainder from manufacturers located in fewer than twelve countries. Bayer (Germany), Caffaro (Italy), Kanegafuchi Chemical Company (Japan),[39] Prodelec (France), Chemko (Czechoslovokia) and a plant in the former USSR all produced PCB mixtures similar to Monsanto's Aroclors 1016 and 1242, and some of these foreign manufacturers produced PCB mixtures similar to 1248, 1254, and 1260 (Erickson, 1997).[40] Nearly 85% of the globally produced PCBs were manufactured by just four companies operating in five countries; *Monsanto* in the U.S. and England, *Bayer AG* in Germany, *Orgsteklo* in Russia, and *Prodelec* in France (IARC, 2016, Table 1.14).

OECD did a survey of member countries and manufacturers to assess the production, use, imports, and exports of PCBs by more than 20 countries around the world during the period 1973 to 1977 (Bareme, 1979; OECD, 1975). Countries surveyed included Australia, Austria, Belgium, Canada, Denmark, Finland, Germany, Greece, Italy, Iceland, Ireland, Italy, Japan, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the U.K., and the U.S.

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[36] Erickson, 2011, p. 139.
[37] Erickson, 2011, p. 139.
[38] Erickson, 2011, p. 139.
[39] Kanegaufuchi produced about 96% of Japan's PCBs from 1954 to 1972, when all production and importation of PCBs were curtailed. The Mitsubishi Monsanto Company in Tokyo produced the balance of the PCBs from 1969 to 1972 and sold them under the Aroclor and Santotherm tradenames (deVoogt and Brinkman, 1989, chapter 3, pgs. 9, 12).
[40] Erickson, 1997, p. 36, Table 2-V.

3.3 PCB PRODUCTION BY HOMOLOG GROUP

PCB-containing products, namely Aroclor mixtures, consisted of mixtures of homologs. Table 3.4 lists the homologs comprising Aroclors sold by Monsanto between 1957 and 1971 (Foster D. Snell Inc., 1973). In addition, Table 3.4 provides a summary of homolog composition of aged[41] Aroclor 1254 (Foster D. Snell Inc., 1973). This is supported by evidence cited by Monsanto, stating that "PCB residues found in wildlife are dominantly penta-, hexa-, hepta-, and octa chloro biphenyls," which it reports are "most similar to Aroclor 1254 and Aroclor 1260 products" (Papageorge et al., 1972). According to a model by the National Research Council (1979), the composition of the estimated 182 million lbs of PCBs considered mobile in the U.S. environment (meaning non-landfilled PCBs) comprised the following homologs:

- 38%, mono-, di-, and trichlorobiphenyl
- 23% tetrachlorobiphenyl
- 39% penta- through decachlorobiphenyl

This breakdown of composition is similar to that reported for homologs in total sales reported by Monsanto, as listed in Table 3.4.

Table 3.4 U.S. Production of Polychlorinated Biphenyl Homologs by Monsanto

PCB Chlorine Homolog	Percent in Monsanto U.S. Sales 1957-1971	Percent in Laboratory Aged Aroclor 1254
0	0.1	<0.1
1	1.3	<0.1
2	14.8	<0.5
3	29.9	1
4	21.9	21
5	16.1	48
6	10.5	23
7	4.2	6
8	1.1	Not detectable

PCB polychlorinated biphenyl
< less than

Reported in Foster D. Snell, Inc, 1973 with data based on Papageorge et al., 1972.

Table 3.5 shows the PCB profile by homolog group for a range of Aroclor mixtures. It is evident from this data that as the Aroclor number increase, the degree of chlorination also increases. This is important for understanding environmental mixtures of PCBs as the pattern will shift toward

[41] "Aged" indicates that the PCB mixture was subject to "weathering" such that the resulting mixture, over time, resembled a more highly chlorinated profile of PCBs due to degradation and sublimation of the less chlorinated PCBs and favoring the more biopersistent and less volatile highly chlorinated PCBs.

the higher chlorinated mixtures over time due to weathering and the sublimation of lower chlorinated PCBs. As such, if Aroclor 1242 is released into the environment, it will resemble 1248 or perhaps even 1254 many decades later due to the weathering process.

Table 3.5 Typical Composition of Polychlorinated Biphenyl Products

PCB Chlorine Homolog	Percent of Aroclor 1221	Percent of Aroclor 1016	Percent of Aroclor 1242	Percent of Aroclor 1254
0	11	<0.1	<0.1	<0.1
1	51	1	1	<0.1
2	32	20	16	<0.5
3	4	57	49	1
4	2	21	25	21
5	<0.5	1	8	48
6	ND	<0.1	1	23
7	ND	ND	<0.1	6
8	ND	ND	ND	ND

PCB polychlorinated biphenyl
< less than
ND none detected

Source: (Papageorge et al., 1972)

3.4 INADVERTENT PRODUCTION

Inadvertently generated PCBs are unintentional by-products from chemical manufacturing processes. In 1984 USEPA identified approximately 200 chemical processes that potentially inadvertently generate PCBs, with 70 processes likely to produce PCBs (Panero et al., 2005). Inadvertent PCBs are formed when chlorine, salts, and hydrocarbons or chlorinated hydrocarbons are mixed and reacted at high temperature (Heine and Trebilcock, 2018; Rodenburg et al., 2010). Primary production sources of inadvertent PCBs include: inorganic and organic pigment manufacture, production of chlorinated solvents, agricultural chemicals, detergent bars, and wood treatment (Heine and Trebilcock, 2018; Oregon Department of Environmental Quality, 2003). Secondary production sources, which result from end products containing PCBs, include paper mills, wastewater treatment plants, and municipal stormwater runoff (Heine and Trebilcock, 2018). The most notable source of these nonlegacy PCBs is the manufacture of pigments and dye due to the requirement of chlorine and heat for production (Chemical Manufacturers Association Special Programs Panel on PCBs, 1981; Grossman, 2013; Guo et al., 2014; Hu and Hornbuckle, 2010; Rodenburg et al., 2010). Pigments and dyes are present in various products such as colored papers, cardboard, plastics, and textiles, which can be released into the environment during their manufacture, use, disposal, or recycling (Guo et al., 2014; Rodenburg et al., 2015).

To address the presence of inadvertently-generated PCBs in manufacturing processes and in the stream of commerce, the USEPA promulgated a rule in 1984 under the Toxic Substances Control Act that allowed PCBs to be manufactured, processed, distributed, and used in commerce provided that the inadvertently-generated PCBs met specified criteria (USEPA 40 CFR 761, 1984). The criteria of the 1984 Rule for inadvertently-generated PCBs are: (i) "detergent bars are limited to less than 5 ppm"; (ii) for all other products, the PCBs must not exceed an average of 25 ppm annually, and shall never exceed 50 ppm; (iii) where PCBs are manufactured or processed and vented to the ambient air, PCB "are limited to less than 10 ppm"; and, (iv) where PCBs are discharged to water, PCB concentrations shall not exceed 0.1 ppm for any "resolvable gas chromatographic peak", and the concentrations in water "are limited to less than 3 micrograms per liter (µg/L, roughly 3 ppb) total Aroclors."[42] When quantifying inadvertently-generated PCBs to determine compliance with the 1984 Rule, the total monochlorinated PCBs are divided by a factor of 50 and dichlorinated biphenyls are divided by a factor of 5.[43] As a result, the annual average concentration of dichlorobiphenyl PCBs in commerce could contain an average concentration of 125 ppm, with a maximum concentration of 250 ppm (Guo et al., 2014).

The discounting of the mono- and dichlorinated biphenyls was justified by the EPA in the 1984 Rule based on a number of considerations and a recognition that these PCBs do not persist in the environment compared to the more highly chlorinated congeners. Specifically, the EPA concluded that the mono- and dichlorinated biphenyls are "(1) [l]ess likely to adsorb to solids; (2) more likely to dissolve in water; (3) more likely to move from natural bodies of water to air; (4) more likely to biodegrade; and (5) less likely to bioaccumulate."[44]

There is little information available on the global production of inadvertent PCBs; however, studies have been conducted to estimate inadvertent PCBs in the U.S. According to a study conducted by the Chemical Manufacturers Association, which surveyed 85 firms in the U.S. chemical industry, 13,800 lbs or 6,260 kilograms (kg) of PCBs are incidentally generated per year (Chemical Manufacturers Association Special Programs Panel on PCBs, 1981; Environmental Defense Fund et al., 1983). The USEPA estimated 75,000 lbs of PCBs to be inadvertently generated annually from 40 chemical processes (Environmental Defense Fund et al., 1983). By combining these studies, the total amount of PCBs inadvertently produced is less than 100,000 lbs (45,400 kg) per year in the U.S. (Chemical Manufacturers Association Special Programs Panel on PCBs, 1981; Environmental Defense Fund et al., 1983). According to one report, less than 1,000 lbs (450 kg) of inadvertently generated PCBs is determined to enter the U.S. environment annually (Environmental Defense Fund et al., 1983).

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[42] USEPA 40 CFR 761, 1984, Fed. Reg. Vol 49., No. 133, p. 28176.
[43] USEPA 40 CFR 761, 1984, Fed. Reg. Vol 49., No. 133, p. 28176.
[44] USEPA 40 CFR 761, 1984, Fed. Reg. Vol 49., No. 133, p. 28179

Recent studies have detected PCB 11 released from products with pigments and dyes, identifying it to be a nonlegacy congener (City of Spokane, 2015; Guo et al., 2014; Hu and Hornbuckle, 2010; Hu et al., 2008; Rodenburg et al., 2015; Rodenburg et al., 2010). According to peer-reviewed literature, an estimated maximum value of annual worldwide inadvertent PCB 11 production from pigments is 17,200 lbs/year (7,800 kg/year) (Guo et al., 2014). The U.S. share of worldwide PCB 11 from pigments based on the U.S. market consumption value of 20% for global organic pigments results in 3,440 lbs/year (1,560 kg/year) (Guo et al., 2014).

The estimated annual production of inadvertent PCBs in the U.S. is 103,440 lbs, which is the sum of 100,000 lbs of accidental PCBs produced from chemical processes and 3,440 lbs of PCBs from pigments. The estimated total production of inadvertent PCBs in the U.S. was estimated by indexing the values of inadvertent PCBs to the annual gross domestic product value for that year from 1947 to 2019 and summing the values, resulting in a total of 5.5 million lbs (U.S. Bureau of Economic Analysis, 2019).[45] The total production of inadvertent PCBs in the U.S. (5.5 million lbs) in relation to the total production of Monsanto PCBs in the U.S. (1,100 to 1,400 million lbs) is estimated to range from approximately 0.4% to 0.5%. Relying on a study conducted by the Chemical Manufacturer's Association, Monsanto estimated the amount of incidental PCBs would be less than 0.5% of the legacy PCBs free in the environment that would expect to degrade by the year 2000 (Monsanto Chemical Company, n.d. Post 1981).

The quantity of inadvertent PCBs produced and released to the environmental is trivial compared to legacy PCBs. Monsanto stated "incidental PCBs lower than 50 ppm constitute a non-problem, whose control is unnecessary and makes absolutely no sense from a risk/benefit viewpoint" (Monsanto Chemical Company, n.d. Post 1981). They characterize the incidental PCB issue as "Hundreds of Pounds versus Hundreds of Millions of Pounds" noting that the inadvertent issue is nothing more than a "PCB footnote" and a "genuine molehill, and rightfully so: the health and environmental risks posed by these incidental PCBs is next to non-existent" (Monsanto Chemical Company, n.d. Post 1981).

In addition to the trivial quantities of PCBs in the environment compared to legacy PCBs, inadvertent PCBs are generally less persistent. The degradation rates of inadvertent PCBs, which are typically less chlorinated, are significantly faster than the degradation rates of more highly chlorinated legacy PCBs. For example, the rate of degradation per year of dichlorobiphenyls is three to six times faster than the rate of degradation per year for tetrachlorobiphenyls, pentachlorobiphenyls, and hexachlorobiphenyls (abundant groups of PCB congeners found in Aroclor mixtures) (Breivik et al., 2002b). For example, the half-life for dichlorobiphenyl PCB 8 is estimated to be 2 years in soil, whereas the half-life of hexachlorobiphenyl PCB 158 is estimated to be 12 years in soil (Breivik et al., 2002b). Furthermore, researchers have found

[45] The value of 13,800 lbs was provided from the year 1981. The value of 75,000 lbs was provided from the year 1982. The value of 3,440 lbs was provided for the year 2006.

more chlorinated heptachlorobiphenyls, such as PCB 180, to have a half-life in soil and sediment of approximately 38 years (Sinkkonen and Paazivirta, 2000).

4.0 POLYCHLORINATED BIPHENYL USES

4.1 GENERAL COMMENTS

As discussed in section 2.3, PCBs were used in open systems such as plasticizers and carbonless copy paper, closed systems, such as electrical transformers and capacitators, and nominally closed uses such as heat transfer or hydraulic fluid. This section discusses the volume of PCBs used in each type of system in the U.S. and globally.

4.2 USES IN THE UNITED STATES

Information on end use applications of PCBs came from three primary sources: USEPA 1976 report, Monsanto Chemical Company memos, and peer-reviewed literature. As seen in Table 4.1, the most common application of PCBs in the U.S. was in closed systems. Specific estimates of end use applications of PCBs in the U.S. from 1930 to 1975 are shown in Table 4.1.

Table 4.1 Estimates of Polychlorinated Biphenyls Cumulative U.S. Production and Usage in Millions of Pounds, 1930-1975

Use Category	Industrial Use	Industrial purchases
Open	Petroleum additive	1
Nominally Closed	Heat transfer	20
Open	Miscellaneous industrial	27
Open	Carbonless copy paper	45
Nominally Closed	Hydraulics and lubricants	80
Open	Other plasticizer uses	115
Closed	Capacitor	630
Closed	Transformers	335
	Total	1,253

Reference: adapted from Table 1.2-1 on page 7 report (USEPA, 1976).

4.2.1 Open Uses

Open end uses of PCBs allow exposure and release to the environment since the PCBs are not contained or controlled. USEPA estimated cumulative PCB usage in open end applications to be 188 million lbs in the U.S. from 1930-1975 (USEPA, 1976). According to Monsanto, the cumulative PCB usage in open-end applications (excluding information for carbonless paper) was 168 million lbs (Monsanto Chemical Company, Circa 1979). In 1971, Monsanto voluntarily terminated the production of PCBs for open end use applications (USEPA, 1976). Among open end use applications, PCBs were most used in plasticizers. Table 4.2 displays the cumulative PCB usage in open end use applications according to industrial category.

Table 4.2 Cumulative Polychlorinated Biphenyl Usage in Open End Use Applications in the United States by Industrial Category Reported in Millions of Pounds from 1930-1978

Open End Use Category	Millions of Pounds	
	1930-1975[a]	1957-1978[b]
Carbonless copy paper	45	--
Miscellaneous industrial	27	22
Plasticizer application	--	144
Other plasticizer uses	115	--
Petroleum additives	1	1.4
Total	188	168

[a] USEPA, 1976
[b] Monsanto Chemical Company, Circa 1979.

4.2.2 Closed Uses

Closed sources fully contain PCBs, preventing exposure to the environment except in the event of accidental spills or leaks, maintenance activities (i.e., refilling) or during disposal. As shown in Figure 4.1, closed electrical system uses (capacitors and transformers) of PCBs were the primary driver of U.S. domestic sales (Monsanto Chemical Company, Circa 1979). In the year 1970, approximately 40 million lbs of PCBs were sold for use in closed electrical systems.

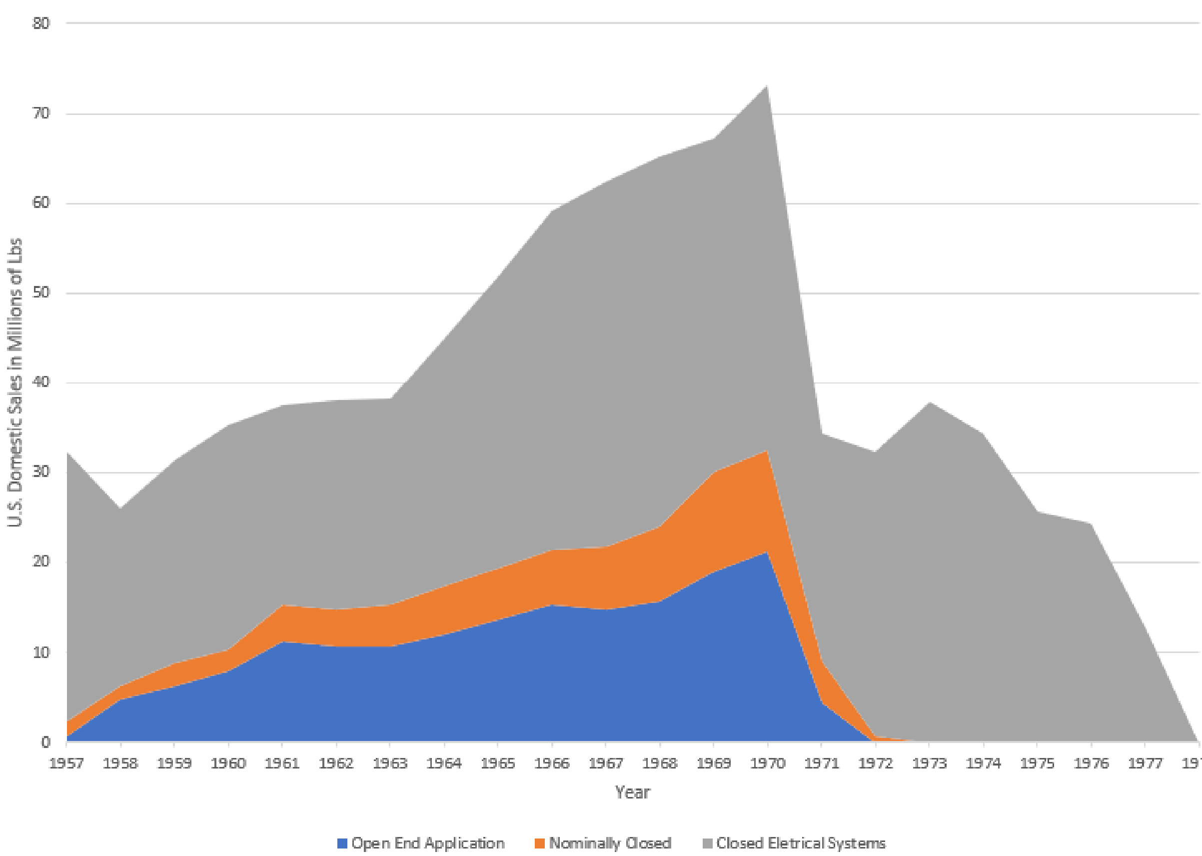

Figure 4.1 U.S. Domestic Sales of PCBs by End Use Application. Chart adapted from data provided by Monsanto Chemical Co. (ca 1979)

USEPA estimated cumulative PCB usage in closed electrical systems to be 965 million lbs in the U.S. from 1930 to 1975 (USEPA, 1976). Reports from Monsanto determined the cumulative PCB usage in closed electrical systems to be 615 million lbs from 1957 to 1978 (Monsanto Chemical Company, Circa 1979). Table 4.3 summarizes the cumulative PCB usage in closed electrical systems according to industrial category.

Table 4.3 Cumulative Polychlorinated Biphenyl Usage in Closed Electrical Systems by Industrial Category in Millions of Pounds,1930-1978

Closed End Use Category	Millions of Pounds	
	1930-1975[a]	1957-1978[b]
Capacitors	630	417
Transformers	335	198
Total	965	615

[a] USEPA, 1976, p. 215 reports that electrical uses began in approximately 1930.
[b] Monsanto Chemical Company, Circa 1979. Extrapolation from 1957 to 1930 assuming an average 19 million pounds per year yields 1,128 million pounds.

4.2.3 Nominally Closed Uses

Nominally closed systems partially contain PCBs, allowing for some exposure to the environment. The application of nominally closed uses of PCBs was the lowest among the use categories. The USEPA estimated cumulative PCB usage in nominally closed systems (i.e., heat transfer, hydraulics and lubricants) to be 100 million lbs in the U.S. from 1930-1975 (USEPA, 1976). According to Monsanto, the cumulative PCB usage in nominally closed systems was 81 million lbs from 1957 to 1978 (Monsanto Chemical Company, Circa 1979). Table 4.4 displays the cumulative PCB usage in nominally closed systems according to industrial category.

Table 4.4 Cumulative Polychlorinated Biphenyl Usage in Nominally Closed Systems by Industrial Category in Millions of Pounds, 1930-1978

Nominally Closed Use Category	Millions of Pounds	
	1930-1975[a]	1957-1978[b]
Heat Transfer	20	20
Hydraulics and Lubricants	80	61
Total	100	81

[a] USEPA, 1976, p. 215, reports that electrical uses began in approximately 1930.
[b] Monsanto Chemical Company, Circa 1979

4.3 GLOBAL USES

PCB usage varied somewhat by country with regards to the percent of PCBs allocated for open, closed, and nominally closed applications. Figure 4.2 displays the percentages of PCB usage during 1973-1977 for countries that dominated PCB production worldwide. As displayed in the

figure, most PCB usage post-1970 was in closed electrical systems. Reports of PCB usage pre-1970 are available for the former West Germany and the U.K. (as shown in Figure 4.3).

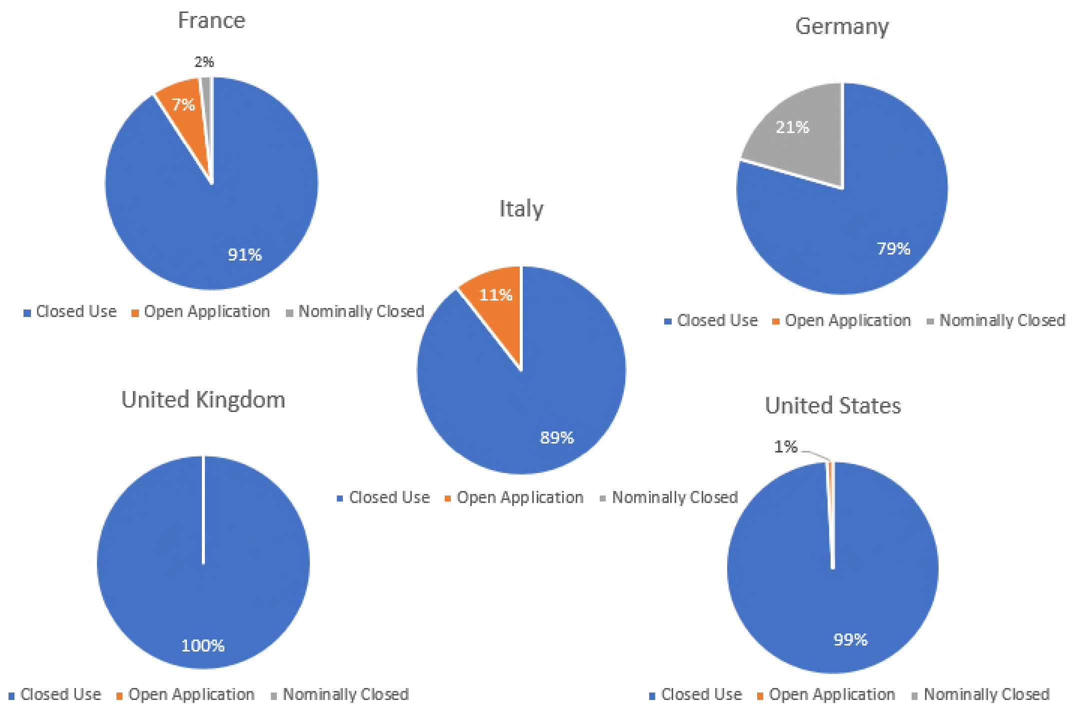

Figure 4.2 Distribution of PCB Usage in France, Germany, Italy, U.K., and U.S. during 1973-1977. Data developed from OECD Report (Bareme 1979)

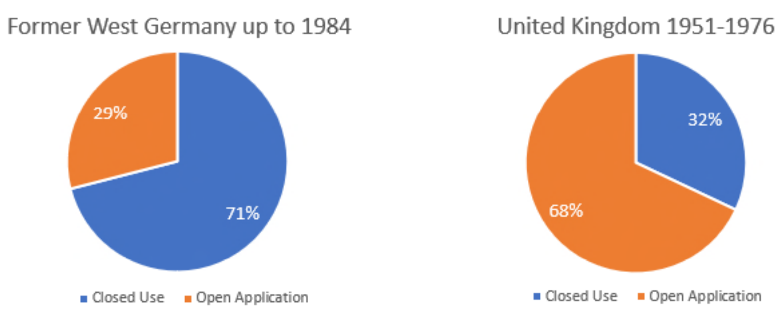

Figure 4.3 Distribution of PCB Usage in Former West Germany and U.K. Data developed from OSPAR Report (OSPAR Commission, 2004)

According to the available data on global end use applications of PCBs, most PCBs were utilized in closed systems. Open end applications of PCBs accounted for approximately 21%, closed electrical systems accounted for approximately 69%, and nominally closed systems accounted for approximately 10% of PCB use worldwide (UNEP, 2019). These usage values correspond generally with the usage of PCBs in the U.S. (refer to Table 4.1), although the U.K. is a notable

exception with 68% open use during 1951-1976. Monsanto was a major producer of PCBs in the U.K., and PCBs released to the U.K. environment are likely attributable to Monsanto.

5.0 PCBS IN THE ENVIRONMENT

5.1 PCB FATE AND TRANSPORT – GENERAL PRINCIPLES

Once released to the environment, PCBs may move within and between environmental compartments. The rate and magnitude of their movements are governed by their physiochemical properties, which are discussed in more detail below. Understanding these processes is necessary to characterize the fate and transport of PCBs around the globe and how this migration could influence the profiles and sources of PCBs in a given compartment.

The following diagram (Figure 5.1) is a general, conceptual model for the fate and transport of chemical contaminants in the environment, including PCBs. The contaminant (PCBs) is released into the air, water and/or land (soil), which are known collectively as environmental compartments. The distribution of PCBs into and among these compartments is governed by several key physicochemical parameters that are discussed in more detail in the following section.

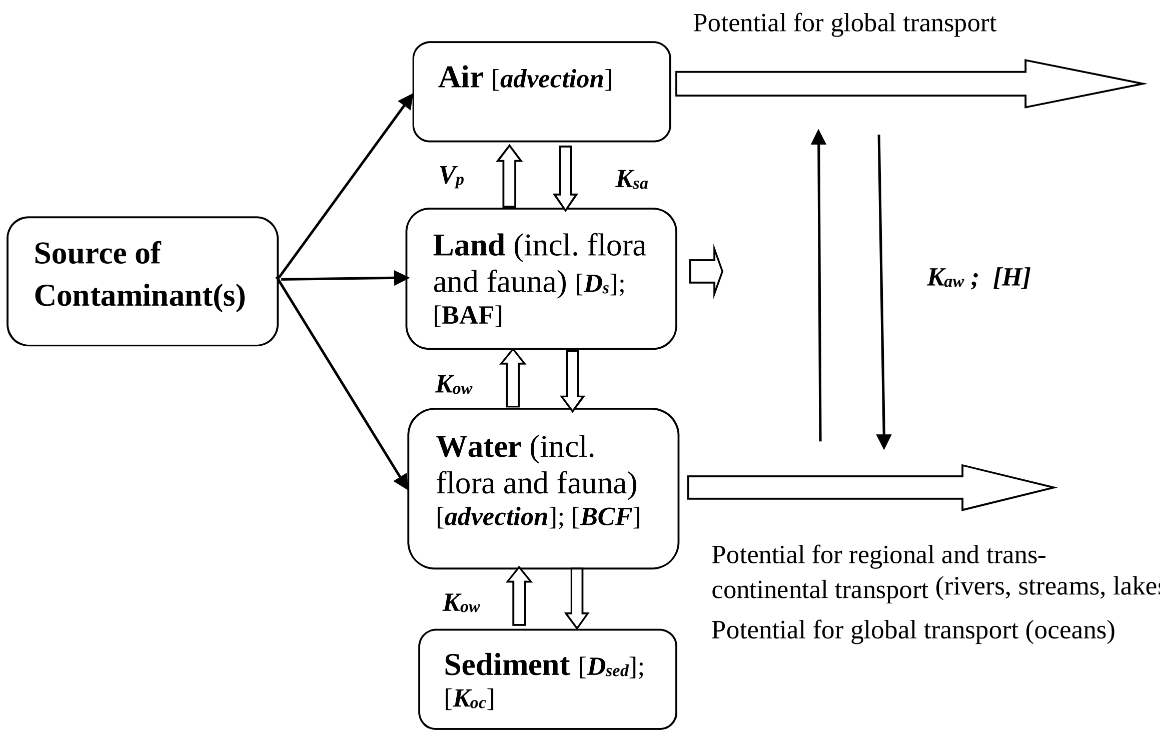

Figure 5.1 Conceptual Model for the Fate and Transport of PCBs

PCB congeners, like other environmental contaminants, partition or separate out from their Aroclor mixtures into various media depending on the properties of the congeners and the materials into which they are migrating. There are several partitioning parameters that are used to characterize the quantity of PCBs that migrate into environmental compartments (Manahan,

1994). These are the octanol-water partition coefficient (K_{ow}), organic carbon-water partition coefficient (K_{oc}), air-water partition coefficient (K_{aw}), and soil-air partition coefficient (K_{sa}) (ATSDR, 2000; Wania and Su, 2004). These measures are simple ratios of the quantity of a particular PCB congener found in one compartment versus another compartment at equilibrium.

These partition coefficients are important for understanding the mobility and accumulation of PCBs in the environment. Because organic compounds, like PCBs, greatly favor compartments rich in organic (i.e., carbonaceous) matter versus water, the resulting partition coefficients, such as K_{ow} and K_{oc}, tend to be very large (in the thousands to millions). These large ratios are simplified by taking the logarithm (base 10) of the ratio to make the numbers easier to report and handle. PCBs have a very high K_{ow}, on the order of 4.7 to 6.8, which means that they have a high affinity for and tend to accumulate in non-polar, organic-rich media, such as soils rich in organic matter, or in fat tissue of individuals exposed to PCBs (ATSDR, 2000).

The parameters of K_{ow} and K_{oc} are strongly correlated, and they are important for understanding the fate and transport of organic compounds outdoors, especially in aqueous systems such as lakes, streams, ponds etc. For example, the bioconcentration factor (BCF)[46] is directly related to the K_{oc} of the pollutant; the higher the K_{oc} the greater the accumulation of PCBs or other lipophilic, persistent compounds in the organism (ATSDR, 2000). The solubility of an organic pollutant in water is inversely related to its K_{ow}, the greater the K_{ow} the *less* soluble the chemical is in water (Manahan, 1994).

Solubility determines the quantity of PCBs that will dissolve in water. The solubility of PCBs ranges from 0.59 milligrams per liter (mg/L) for Aroclor 1221 to 0.0027 mg/L for Aroclor 1260, i.e., the higher chlorinated Aroclors are less soluble in water (ATSDR, 2000). By comparison, the solubility of toluene, a common organic solvent, in water is 520 mg/L. This means that the transport of PCBs from soil to groundwater or surface water is inhibited. However, PCBs can be transported to surface water via entrainment of contaminated soil particles in surface water runoff. Given PCBs' high affinity for organic material and very low solubility in water, the vast majority of PCB molecules will remain attached to these sediment particles, unless or until they are re-suspended by mechanical forces (e.g., dredging) or they are ingested or absorbed by biological organisms such as fish (ATSDR, 2000).

The rate at which PCBs evaporate or sublimate[47] from water or soil and become airborne depends, in part, upon the volatility of the individual congener, also known as the vapor pressure.

[46] The amount of a persistent organic pollutant, such as PCBs, that accumulates in the tissue of an aquatic organism compared to the concentration of the pollutant in the water at equilibrium, abbreviated as BCF.

[47] Sublimation is the process by which a chemical compound transitions from its solid phase to a gas or vapor phase without going through the intermediate liquid phase. An instructive example of sublimation

The congener's vapor pressure, the properties of the water or soil, and environmental parameters (e.g., temperature) are characterized by the air-water (K_{aw}) or soil-air partition (K_{sa}) coefficients, respectively, and describe the sublimation of PCBs from water and soil (Wania and Su, 2004). PCBs generally have low vapor pressures, which limits their volatilization from their solid or liquid state into a gaseous and thus airborne state. The lower chlorinated and lower molecular weight congeners approach 0.001 Torr[48] while the more highly chlorinated and higher molecular weight congeners are generally less than 0.00001 Torr (ATSDR, 2000). For comparison purposes, xylene or toluene (common solvents found in oil-based paint and paint thinner), range from 7 to 28 Torr at typical ambient conditions (Toxnet, 2016a; 2016b). PCBs are at least 1,000 to over 10,000 times less volatile than these common solvents. Therefore, they are considered semi-volatile compounds, as they do not volatilize readily.

Vapor pressures for the various commercially produced Aroclors span about two orders of magnitude, or 100 times difference in volatility between the most volatile and the least volatile mixtures (ATSDR, 2000). The varying emission rates of each PCB congener will change the profile of the mixture in the contaminated medium or compartment over time due to differential vaporization, a process, in combination with biotransformation and environmental degradation, known as "weathering." For example, if Aroclor 1248 is released to the environment, over time, as the more volatile congeners evaporate or sublimate into the air and the less chlorinated congeners are degraded more quickly, the released mixture may begin to resemble the congener profile of Aroclor 1254.

Once the PCBs are in an environmental compartment, the migration of a PCB congeners within the compartment is determined by its diffusivity. Diffusivity is a measure of the congener's (or other substance's) ability to migrate within media such as soil (D_s) or sediment (D_{sed}). The higher the "diffusivity" of a PCB congener with all other factors being equal, the greater its ability to migrate within and through the solid. Diffusivity is characterized by the congener's or a substance's "diffusion coefficient," a parameter that describes quantitatively the mobility of a chemical species in a given medium. It represents the innate properties of the specific PCB congener or substance and the properties of the medium, such as porosity.

The rate at which a PCB congener or any substance will move through the medium is determined by its diffusion coefficient and the concentration gradient (i.e., the difference in concentration from one point to another in the material). The rate of diffusion is affected by: (i) the temperature in the surrounding environment, (ii) the porosity of solid materials (e.g., soil is more porous in

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is when ice cubes lose mass and shrink while in the freezer as the water molecules transition from the solid phase (ice) to the vapor phase over time.

[48] A unit of measure for pressure, the reference pressure of the atmosphere at sea level is 760 Torr, which is equivalent to 760 mmHg.

comparison to concrete or brick), and (iii) the concentration gradient. The greater the porosity, the less resistance to diffusion and the greater the diffusion rate of PCBs within solid materials.[49] PCBs are known to accumulate in ecological and biological systems, such that as one moves up the trophic levels (the organism's position on the food chain), more PCBs accumulate in the fat tissue of the organism. This is in the process known as biomagnification or bioaccumulation, and the parameter is noted as the biomagnification or bioaccumulation factor (ATSDR, 2000). Organisms or species at the highest trophic level (e.g., humans, non-human mammals) will incorporate some of the PCBs from the lower trophic level species into their tissue, resulting in increased concentrations of PCBs over time such that the burden of PCBs in the organism will correlate with age (all other factors being equal). This fact, and more specifically, the BCF is often used to establish allowable levels of PCBs in lakes, rivers and streams.

As a general class of chemical compounds, PCBs in bulk quantities are not highly mobile in the environment. This is because they are not very volatile, meaning their rates of evaporation or sublimation are comparatively low: they exhibit low or very low solubility, so they are not easily dissolved in and transported by water. PCBs have high or very high K_{ow} and K_{oc} values, which means a substantial amount of PCBs released to the environment will tend to remain attached to material rich in organic matter. This is not to say that PCBs are immobile in the environment. Indeed, there is a fraction of PCBs, especially the less chlorinated congeners that will more readily migrate within and between environmental compartments. PCBs can be found at low concentrations (ppt and ppq levels) virtually everywhere on the planet. However, bulk quantities of PCBs tend to remain geographically confined to where they were released into the environment, unless other external forces (e.g., storms, floods, fires, etc.) act on the media/compartments in which they are contained and mobilize them.

5.2 GLOBAL CYCLING

The physiochemical properties described above, along with the global air and ocean currents and environmental factors such as temperature, will determine the fate of mobile PCBs. Given the global circulation patterns, PCBs will tend to move from low latitudes (tropical or sub-tropical) to higher latitudes (temperate to polar). This fact is borne out by sampling ocean water where higher PCB levels are noted in the mid to higher latitudes, and the PCBs concentrate in the northern hemisphere where PCB production and use was the greatest historically (Tanabe, 1988). Using a global distribution model known as Globo POP to model the circulation of PCBs, researchers demonstrate over the course of several decades that lighter weight PCBs, particularly the mono thru tetra PCBs, will migrate from the temperate regions where most PCBs were generated and released to the environment to boreal and ultimately polar regions (Wania and Su, 2004). However, the heavier and more chlorinated PCBs (hexas thru octas) demonstrate very little movement across climatic regions, generally remaining in the areas where they were

[49] This is true provided the temperature and the concentration gradient remain the same.

released (Wania and Su, 2004). Quantitatively, Wania and Su demonstrate that, of the total released PCBs, only about five to ten percent migrate to the boreal regions and significantly less migrate to the polar or artic regions. The researchers validated their model by comparing sampling results from 2000 in the temperate and boreal regions to actual data in European woodlands, which showed excellent agreement between the model and the sampling results (Wania and Su, 2004).

Work by Gouin and Wania further explores the migration into the artic regions of the globe. Their work, based on the Globo POP model, developed the “artic contamination potential” or “*e*ACP” estimate (Gouin and Wania, 2007). They developed descriptive categories of chemicals based on their overall behavior in the environment. The categories include fliers, swimmers, single hoppers, and multiple hoppers. PCBs were considered multi hoppers, meaning they would distill and re-condense multiple times before they were degraded and/or settled into a compartment. The researchers modeled the behavior of these chemical categories over a 100 year period under differing release scenarios (pulse, bell curve, steady) (Gouin and Wania, 2007). They found that the multiple hoppers (PCBs) approached 4% of the total released PCBs and peaked about 35 years after being released based on a bell curve emission scenario (Gouin and Wania, 2007).

These values provide important insight into the potential for inter-regional or inter-zonal migration of PCBs globally. More importantly, the fraction of released PCBs that migrate into the boreal and artic regions can be used to estimate the potential composition and source of PCBs detected in the U.S. environment, particularly in the more northern latitudes.

5.3 PCB INVENTORIES IN ENVIRONMENTAL COMPARTMENTS

PCBs in the environment emerged as a global issue when Soren Jensen discovered, quite by accident, these chemicals in his biological samples. Jensen was conducting routine screening for pesticides when he encountered the unidentified compounds. He collected eagle feathers from a museum collection to determine when these compounds first appeared in biological samples. Jensen was able to identify PCBs in feathers dating back to as early as 1944, well before widespread use of chlorinated pesticides (Versar Inc., 1979). Based on this finding, he knew there was another bio-persistent, chlorinated organic compound in his samples that was in the stream of commerce prior to the use of chlorinated pesticides. He later identified these compounds as PCBs. His findings were published in the journal New Scientist in 1966 and his work became the impetus to characterize the nature and extent of PCBs in the natural environment.

Jensen’s findings were confirmed by others (Monsanto Chemical Company, 1969b; Risebrough et al., 1968); and the research, regulatory and manufacturing communities began investigating how PCBs had entered the environment as well as their fate and transport globally.

In or about 1969, Monsanto developed a "PCB Environmental Pollution Abatement Plan" to manage PCBs and to mitigate their impact on the natural environment (Monsanto Chemical Company, 1970; Papageorge, 1970). In the Plan, the authors highlighted various pathways for PCBs to enter the environment. They acknowledged that, "[a]lthough there may be some soil and air contamination involved, by far the most critical problem at present is water contamination." The Monsanto Plan organized the pathways into two basic categories; open and indirect pollution.

Open pollution pathways included: (i) fluids, which were noted as "the most open source of pollution because of their mobility"; (ii) PCB products used in electrical, heat transfer and industrial applications that were generally discharged directly to the sewer; and (iii) direct release to the environment from using PCBs in de-dusting applications for unpaved roadways.

Indirect pollution pathways included: (i) shipping containers contaminated with PCBs; (ii) leaks from electrical and heat transfer applications; (iii) cross-contamination from compressors that used PCB fluids as a lubricant/coolant; and (iv) leaching of PCBs used as a plasticizer in paints and coatings as well as printing inks, paper coatings and certain adhesives.

No additional characterization of the fate of the PCBs was provided in the plan and no attempt was made to estimate the quantities of PCBs released to the various environmental compartments.

The authors evaluated three options to address the PCB environmental contamination issue. These options included: (i) do nothing; (ii) discontinue the manufacture of all PCBs; and (iii) "respond responsibly, admitting that there is growing evidence of environmental contamination by the higher chlorinated biphenyls and take action as new data is generated to correct the problem" (Monsanto Chemical Company, 1969a).[50] This ultimately led to Monsanto voluntarily terminating production of PCBs for open or "non-controllable end uses" in late 1970 and included: (i) termination of PCBs for use as plasticizers and non-biodegradable PCBs for non-controllable uses; (ii) discontinuing the use of Aroclor 1242 for carbonless copy paper; (iii) phase out of non-biodegradable PCBs in hydraulic fluids; and (iv) implementation of a fluid collection and regeneration program (Bock et al., 1970).[51]

In 1972, Ian Nisbet, a researcher with the Massachusetts Audubon Society and Adel Sarofim, a chemical engineering researcher at the Massachusetts Institute of Technology published one of the earliest journal articles that outlined the release, fate, and transport of PCBs in the environment (Nisbet and Sarofim, 1972). They identified several pathways for PCBs to enter the environment, including: (i) leaks from transformers and heat exchangers; (ii) leaks from

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[50] Monsanto 1969, MONS 35381.
[51] Boch, 1969, TOWOLDMON0003483 - TOWOLDMON0003485

hydraulic systems; (iii) spills and leaks during the manufacturing and handling of PCBs; (iv) vaporization to the ambient air; and (v) disposal. The researchers estimated that approximately 0.5 million tons or 1,000 million pounds of PCBs had been released to all the environmental compartments, of which 180 million pounds had been released to the air, water and sediment. The authors estimated that approximately 120 million pounds had been discharged to the fresh and coastal water systems and another 60 million pounds to the atmosphere, for a total of 180 million pounds released to the environment (Nisbet and Sarofim, 1972).

In the same year, the Interdepartmental Task Force (ITF) on PCBs[52] produced their report, which was the result of a six-month review of PCBs in the environment (Interdepartmental Task Force on PCBs, 1972). Their findings, in general, echoed the approach taken by Monsanto two years earlier: terminate the use of PCBs for non-controllable end uses and implement measures to minimize the release of PCBs to the environment. The ITF also advocated for the continued use of PCBs as a dielectric fluid given the superior fire safety performance of this fluid and the impact to the continuity of electrical service that could result from a wholesale ban and replacement of the Askarels.[53]

The ITF report also highlighted waterways as, “probably the principal sink and transport mechanism for PCBs” (Interdepartmental Task Force on PCBs, 1972). They examined the PCB load or burden from municipal and industrial discharges to waterways and determined that approximately 12 million pounds of PCBs were released annually to the rivers and waterways (ITF, 1972). They found that municipal and industrial discharges are a critical component of the total PCB burden on the environment, as noted by Monsanto in its “PCB Environmental Pollution Abatement Plan” (Monsanto Chemical Company, 1969a)

USEPA released a comprehensive report on the industrial use and environmental distribution of PCBs in the U.S. in 1976 (USEPA, 1976). The report developed yearly loss factors for PCBs by type of use, based on the amount of PCBs in commerce. Specifically, loss factors were assigned as follows: closed uses (5%), hydraulic and heat exchange fluids (60%), plasticizers (25%), and miscellaneous applications (90%) (USEPA, 1976). The lead author, Robert Durfee, Ph.D., of Versar, Inc., noted that the loss factors, “can be the subject of considerable controversy.” However, he continued, “[s]uffice it to say that the choices made appear to be reasonable based on the widely varying information considered” (USEPA, 1976). These loss factors were applied to the Monsanto production numbers to determine releases to the environment from 1930 to 1974.

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[52] Formed on September 1, 1971, to coordinate scientific efforts in the government regarding PCBs. Task Force had representatives from the U.S. Department of Agriculture, Department of Commerce, Environmental Protection Agency, Department of Health, Education and Welfare, and the Department of the Interior.

[53] Askarels was the common term used to denote fluids used largely in transformer applications. Askarels were a blend of PCBs and other chlorinated organic compounds, such as trichlorobenzene.

USEPA estimated that 172.8 million pounds of PCBs had been released to the environment. This is remarkably close to the estimate of 180 million pounds proposed by Nisbet and Sarofim several years earlier. Dr. Durfee of Versar, Inc., noted that the total environmental load of PCBs can be reduced by 20 to 30 million pounds to account for environmental degradation and destruction of the less chlorinated isomers or homolog groups (USEPA, 1976). This results in a total environmental burden of PCBs of approximately 150 million pounds as of 1974. Aroclor 1242, the most widely used PCB mixture, was also estimated to be the type of PCB mixture found most frequently in the environment, and tetra- and penta-chlorodiphenyls were the most abundant homologs in the environment.

In 1979, the National Academies of Science (NAS), Committee on the Assessment of Polychlorinated Biphenyls in the Environment published a report regarding the nature of the PCB contamination "problem" and provided "alternatives for reducing the current substantial levels of environmental contamination from PCBs" (National Research Council, 1979). The committee set three objectives for itself, including: "(1) to develop a model of PCB distribution throughout the environment with estimates of current reservoir burdens; (2) to analyze the economic impact of various control options; and (3) using PCB data as the test case, to assess the effectiveness of the proposed EPA testing guidelines for evaluating toxic substances" (National Research Council, 1979).

The report noted that the majority of PCBs in the U.S. environment likely came from sources within the U.S. The report stated, "[i]t also can be inferred, with some certainty, that PCBs entering the U.S. through commercial imports or via transnational atmospheric transport have been inconsequential when compared to the amounts entering the U.S. environment via domestic routes" (National Research Council, 1979). The Committee, relying on the work of Dr. Durfee (USEPA, 1976), estimated that about 181 million pounds of mobile PCBs had been released to the environment as of 1977, with nearly twice that amount in landfills (National Research Council, 1979). This total release to the "mobile environmental reservoirs (MER)" is similar to the 180 million pounds estimated by Nisbet and Sarofim (1972) and the 172.8 million pound figure proposed by Durfee, prior to adjusting for any potential degradation. The report continues, "[l]osses from open-end and nominally closed systems in service undoubtedly have been large and have contributed to contamination of soil, water, and atmosphere" (National Research Council, 1979).

In 1989, Shinsuke Tanabe of Ehime University in Japan published additional information on the partitioning of PCBs into various environmental compartments on a global basis (Tanabe, 1988). He estimated that approximately 825 million pounds of PCBs have been released from the global production and use of PCBs, representing about 31% of the total global PCB production. Oceans were determined to be the most important environmental compartment containing more than one-half (62%) of the mobile PCBs. Sediments were the next highest environmental

compartment, containing nearly 35% of the mobile PCBs. Taken together, the oceans and sediments account for 97% of the total PCB environmental burden.

Improvements have been made to estimate PCB production, usage, and releases to the environment. This information coupled with advancements in fate and transport modeling have improved our understanding of how PCBs move in the environment. Breivik, et. al. (Breivik et al., 2007; Breivik et al., 2002a; Breivik et al., 2002b) have produced several influential papers on the fate and transport of PCBs, building on the work of the authors discussed above. Breivik's work improved upon the fate and transport modeling of PCBs and included more recent information on the production and usage of PCBs globally.

Table 5.1 Summary of the Polychlorinated Biphenyl Burden in Environmental Compartments

Study/Source[1]	Area of Study	Environmental Compartments, in millions of pounds (% relative to total PCB production)					
		Air	Fresh Water[2]	Oceans[2]	Sediment	Land	Biota
Nisbet & Sarofim (1972)[3]	North America	60 (1%)	120 (12%)			Not applicable	Not applicable
ITF (1972)[4]		ITF referred to estimates from Nisbet and Sarofim			5.8	Not applicable	Not applicable
USEPA/Durfee (1976)[5]		Total mobile release to the environment, adjusted for degradation 150 (10.7%)					
NRC (1979)[6]		0.04 (<0.01%)	Low: 0.03 (<0.01%) High: 0.04 (<0.01%)	Low: 13.2 (0.94%) High: 145 (10.4%)	Fresh -Low:3.1 (0.2%) -High: 15.7 (1.1%) Ocean -Low: 1.5 (0.1%) -High: 6.0 (0.4%)	Lithosphere -Low: 0.31 (0.02%) -High: 6.2 (0.4%) Sludge 10.6 (0.8%)	Fresh: 0.07 (<0.01%) Ocean: 0.07 (<0.01%)
Tanabe (1988)[7]	Global	2.84 (0.11%)	7.72 (0.29%)	512 (19.3%)	287 (10.8%)	5.29 (0.20%)	10.1 (0.38%)
Breivick (2002)[8]		Global release to the environment of 22 PCB congeners: High: 202 (16.2%) Med: 17 (1.4%) Low: 1 (0.08%)					
Breivick (2007)[9]		Releases to the environment of total PCBs: Default: 37.7 (1.29%) High: 345 (11.81%)					

(1) Refer to reference section of this report for the full citations of studies.
(2) Includes dissolved PCBs and biota, where these values were provided separately.
(3) Nisbet and Sarofim (1972): All values for North America for period of 1930-1970. Cumulative input values only available for air and fresh and coastal waterways. 600 million pounds is estimated to be in landfills, although no estimate was provided for PCBs that may leach from their containers. Authors estimate that 1/3 of the PCBs release to the air and ½ of the PCBs released to the water have been degraded.
(4) Interdepartmental Task Force (1972): Values based on Nisbet and Sarofim. ITF estimated sediment values in the U.S. based on reported values measured in the environment.
(5) Durfee (1976): Author only provides estimates for total release to the environment and estimates based on use and homolog grouping for the U.S. Direct estimates by environmental compartment are not provided. Values were estimated based on a mass-balance model that was tested using parameters for Lake Michigan. This model, more limited in scope, found that 67% of the PCBs accumulated from 1930-1975 partitioned into solution, approximately 11% partitioned into the sediment, and only about 2.5% partitioned into the biota. The model identified evaporation loss (13% of the total input) as the main pathway for PCBs moving out of the Lake Michigan system (although PCB degradation was not considered in the model).
(6) National Research Council (1979)
(7) Tanabe (1998): The terrestrial/coastal and open ocean values are combined for air levels, ocean values and sediment values. Nearly all PCB load in sediment is from terrestrial/coastal estimates. Most of the biota PCB burden is from terrestrial/coastal estimates, and land estimates are for released PCBs. PCBs in service, in landfills, and in dumps are estimated at 1,730 million pounds. World-wide production was estimated at 2,650 million pounds.
(8) Breivik (2002): Data is not provided for individual environmental compartments. Production and release numbers are based on 22 PCB congeners that, together, represent approximately 43% of total PCB production globally. Emission factors were calculated based on production, use, accidental release, and disposal of PCBs. Percentages are based on an estimated 1.25 million pounds of 22 PCB congeners produced worldwide. High and low estimates were calculated by altering the inputs of the mass-balance model to account for uncertainties.
(9) Breivik (2007): This paper improved early estimates (2002) by including additional information on the production of PCBs and providing a more refined fate and transport model that better approximated use and failure rates of products that contain PCBs, thus improving the emission factors both spatially and temporally. Release values are adjusted to account for the amount of 22 PCB congeners in the total production volume of PCBs.

6.0 MONSANTO'S PCBS IN THE ENVIRONMENT OF THE UNITED STATES

The main objective of this work is to quantify the likely percentage of PCBs in the environment of the U.S., State of Washington, and City of Spokane that are attributable to Monsanto's production. This work relied upon documentation produced by Monsanto, government documentation, and peer-reviewed literature to develop a mass-balance model of PCBs in the U.S. environment attributable to Monsanto's production. Monsanto recognized that its PCBs have contaminated the environment in the U.S. in its PCB Environmental Pollution Abatement Plan. Specifically, the Plan states that, "[a]lthough Monsanto is most probably responsible for the U.S. contamination and jointly responsible with MCL for the United Kingdom problem, we cannot accept responsibility for the world" (Monsanto Chemical Company, 1969a).[54]

6.1 PCBS IN THE UNITED STATES

6.1.1 Framework

A mass-balance model is a widely accepted mathematical model, which utilizes specific inputs, outputs, and assumptions to quantify estimates of PCBs (AMAP and Arctic Monitoring and Assessment Programme, 2000; Breivik et al., 2007; Gouin and Wania, 2007; Wania and Su, 2004). The mass-balance model employed in this study determined the amount PCBs in the U.S. by relying upon global production numbers. Production numbers were deemed to be the most accurate values available, given the limited data available, compared to the total expected loading of PCBs in the environment. To quantify PCBs in the environment of the U.S., the model first accounted for production, importation, and exportation of PCBs. The model then applied an emission factor on consumption values of PCBs to estimate the quantity of PCBs released to the U.S. environment. The emission factor was derived from previously conducted work that assessed the releases of PCBs to the environment based on multiple scenarios of accidental release, use, and disposal for open, closed, nominally closed and small capacitor uses (Breivik et al., 2007; Breivik et al., 2002b).

In simple terms, the total amount of Monsanto-generated PCBs released to the environment was estimated by multiplying by an emission factor by the total amount of PCBs consumed in the U.S. that were produced by Monsanto. This quantity was discounted by the mass of PCBs released to the environment by non-Monsanto entities calculated using the same production-based emission factor. The quantity of Monsanto's PCBs in the environment was discounted further to account for the global cycling of PCBs out of the U.S.[55] The amount of PCBs

[54] Monsanto 1969, MONS 035377.

[55] As discussed in section 5.2, less than 5% to 10% of PCBs released are globally cycled (Gouin and Wania, 2007; Wania and Su, 2004). The model in this study applied the 5% assumption to PCBs released inside and outside of the U.S. to estimate the quantity of PCBs leaving and entering the U.S. via global cycling. To be conservative, the model assumed that none of the globally cycled PCBs were

inadvertently generated and PCBs released by other producers/importers were added to the environmental reservoir of PCBs in the U.S. This value was then divided into the total amount of PCBs released into the U.S. environment by Monsanto to estimate the proportion of PCBs attributed to Monsanto.

It is important to note that this framework characterizes emissions to the air. Once in the air, the PCBs are mobile and can partition into various environmental compartments as discussed in more detail in section 5.0 of this report. What this framework does not address are the quantities of PCBs that may be present in a locality contained within various environmental compartments (e.g., soil, landfills) due to bulk releases of PCBS (e.g., spills, disposal). As noted previously in section 5.1 of this report, bulk quantities of PCBs released to the environment are not very mobile and tend to remain in the general area or region where they were released. Therefore, the estimates of PCBs in the environment provided in the following sections should be viewed as likely minimum estimates of the total environmental load of Monsanto's PCBs.[56]

6.1.2 Mass-Balance Results

This report utilizes multiple mass-balance models with varying inputs and assumptions to determine the range of PCBs in the U.S. environment likely attributable to Monsanto. Figure 6.1 displays the framework of the primary mass-balance model relied upon in this report.
The starting point of the model is 2,990 million lbs of globally produced PCBs (refer to Table 3.1 in this report). The 2,990 million lbs comprise 1,401 million lbs produced by the U.S. and 1,589 million lbs produced by other countries. The two U.S. commercial manufacturers of PCBs were Monsanto, which produced 1,400 million lbs, and Geneva Industries, which produced 1 million lbs. Of the 1,401 million lbs in the U.S., 150 million lbs were exported and 3 million lbs were imported, resulting in 1,254 million lbs used in the U.S. (Durfee, 1976). To estimate emissions of PCBs in the U.S. environment, the model applied an emission factor of 11.8% to the total consumption value of 1,254 million lbs, resulting in 148 million lbs released to the environment (Breivik et al., 2007). This results in emissions of PCBs to the environment that are consistent with earlier studies (refer to section 5.3 of this report). The PCB emissions attributable to Monsanto were determined by applying the emission factor of 11.8% to Monsanto's domestic consumption value of 1,250 million lbs resulting in 147.5 million lbs. PCB emissions attributable to Geneva Industries were determined by multiplying the production value of 1 million lbs by the emission factor of 11.8%, resulting in 118,000 lbs. PCB emissions attributable to imports were

associated with Monsanto, which underestimates the true environmental burden of PCBs attributable to Monsanto, that both produced and exported PCBs outside the United States.

[56] Monsanto manufactured more than 99% of the commercial-produced technical mixtures of PCBs consumed in the United States. Therefore, any PCBs that were accidentally or intentionally released to the U.S. environment from the use, storage, handling or disposal of commercial PCB mixtures are Monsanto-produced PCBs, excepting the vanishingly small amount that may be released from Geneva Industries and users of its PCBs and releases from the very small quantity of imported PCBs.

determined by multiplying the import value of 3 million lbs by the emission factor of 11.8%, resulting in 350,000 lbs. The model assumed that 100% of the 5.5 million lbs of inadvertent PCBs are released to the environment, reducing the amount of PCBs that could be attributable to Monsanto.

The model also accounted for PCBs entering the U.S. environment from global cycling by multiplying the value of PCBs in the international environment by 5% (Gouin and Wania, 2007; Wania and Su, 2004). The model assumed none of the PCBs cycling into the U.S. are associated with Monsanto.[57] The quantity of PCBs released to the international environment was calculated by multiplying the international production value of 1,589 million lbs by the 11.8% emission factor resulting in a value of 187.1 million lbs. The value of PCBs in the international environment (187.1 million lbs) was then multiplied by the global cycling factor of 5% for a value of 9.4 million lbs.

The model also calculated PCBs leaving the U.S. environment from global cycling by multiplying the value of PCBs in the U.S. environment from Monsanto by the global cycling factor of 5%. The model assumed all the PCBs cycling out of the U.S. are associated with Monsanto. The amount of Monsanto PCBs released to the U.S. environment was (147.5) multiplied by the global cycling factor of 5% for a value of 7.4 million lbs.

The total amount of PCBs released to the U.S. environment was calculated by summing: (1) the PCBs released to the U.S. environment based on consumption (148 million lbs); (2) PCBs released to the environment based on inadvertently produced PCBs (5.5 million lbs); and (3) PCBs globally cycled into the U.S. (9.4 million lbs). The quantity of PCBs globally cycled out of the U.S. (7.4 million lbs) was then subtracted from this value. According to the mass-balance model, Monsanto PCBs account for 90% (140.1 out of 155.5 million lbs) of total PCBs released to the U.S. environment.

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[57] This assumption favors Monsanto because it is known that Monsanto produced PCBs in other countries (e.g., United Kingdom, Japan) and exported PCBs internationally; therefore, at least some PCBs cycling into the U.S. are likely to be associated with Monsanto.

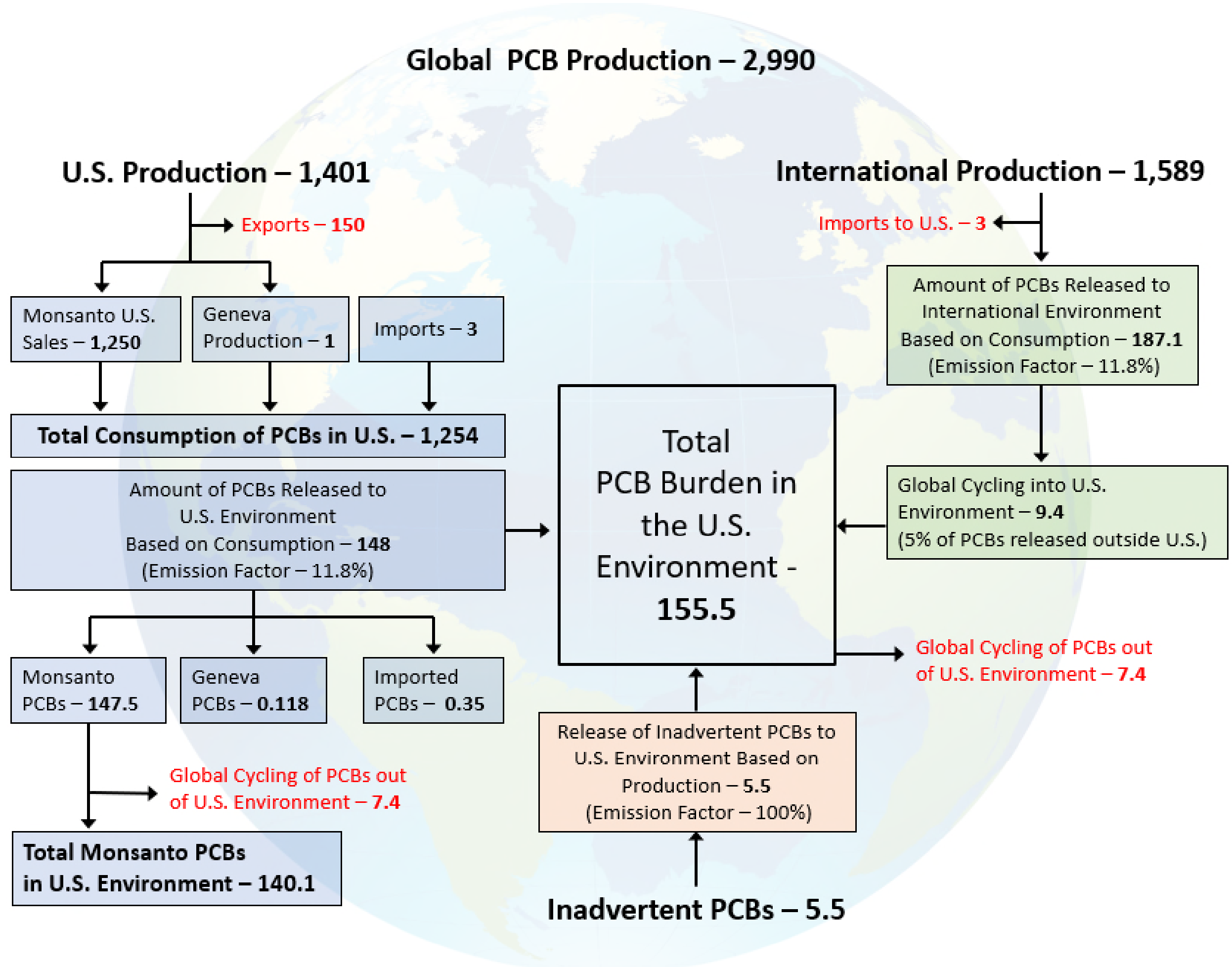

Figure 6.1 Diagram of the primary mass-balance model used to estimate the quantity of PCBs released to the environment in the U.S. (units in millions of lbs) incorporating an emission factor of 11.8% for Monsanto, Geneva, and imported PCBs and an emission factor of 100% for inadvertent PCBs. 11.8% emission factor, based on production figures, is calculated for the period 1930-2005 (Breivik et al., 2007). Through 2100, the emission factor only increases marginally to 12.3% of total PCB consumption. Using 2005 estimates appropriately characterizes emissions through 2019. The red text indicates PCBs leaving the U.S. Note that the numbers are rounded in this figure.

6.1.3 Mass-Balance Sensitivity Analyses

Two sensitivity analyses were conducted to ascertain the likely variability associated with the primary mass-balance output. First, a scenario-based sensitivity analysis was conducted by generating combinations of inputs and assumptions to determine the range of PCBs likely attributable to Monsanto.[58] The complete results of the scenario sensitivity analysis are reported in Appendix A. The scenario sensitivity analysis determined the overall range of PCBs in the U.S. environment likely attributable to Monsanto to be 86.1% to 93.8%.

[58] Estimated inputs and assumptions were obtained from Durfee, 1976 and Breivik et al., 2007.

Second, a Monte Carlo simulation was conducted to further test the variance associated with the primary mass-balance output. The Monte Carlo simulation was conducted using the Two-Dimensional Monte-Carlo package in R statistical software for 10,000 iterations (Pouillot et al., 2016). The assumptions applied to the Monte Carlo simulation are reported in Appendix B. The Monte Carlo simulation determined the 95% confidence interval of PCBs in the U.S. environment likely attributable to Monsanto to be 83.2% to 91.6%.

As stated previously, these estimates should be viewed as likely minimum proportions of the total environmental load of PCBs attributable to Monsanto. These estimates do not include commercially produced PCBs that remain in various environmental compartments that were released during the use, handling, storage, and disposal of PCBs, which would be almost exclusively attributed to Monsanto.

6.2 PCBS IN THE STATE OF WASHINGTON

6.2.1 Impaired Waterbodies

The State of Washington has many waterbodies that are impacted by PCBs. There are 195 waterbodies identified by the Department of Ecology classified as a Category 5 impacted waterway[59] (refer to Table 6.1) due to the level of PCBs associated with the waterbodies (State of Washington Department of Ecology, 2019). Most of the waterbodies (188 of the 195) are classified as impacted based on the levels of PCBs found in fish and other aquatic organisms. The remaining seven water bodies are classified as impacted due to the levels of PCBs found in the sediment.

Table 6.1 Impaired Waterbodies Due to Polychlorinated Biphenyls, State of Washington (2014)

Waterbody Type	Number of Impacted Waterbodies
Lakes	63
Rivers/Streams	59
Large River	20
Marine	53*
TOTALS	195

* 7 of 53 classified based on PCBs in sediment

Source: https://apps.ecology.wa.gov/ApprovedWQA, accessed August 1, 2019.

PCB impaired waterways are concentrated in a relatively small number of counties, although virtually all 39 counties are impacted. As shown in Table 6.2, the five counties with the highest

[59] A Category 5 classification refers to waterbodies that exceed water quality criteria or standards based on data and require a water improvement project, or Total Maximum Daily Load (TMDL) plan to limit the discharge of pollutant(s) in order to achieve water quality criteria. These waterbodies are also known as 303(d) listed waterbodies, in reference to the regulation that governs the classification.

number of PCB-impacted waterways account for 82 of the 195 impaired waterways. King, Spokane, and Pierce counties contain the greatest number of impacted waterways, with most of the marine impaired waterways in King and Pierce Counties and most of the impaired rivers and streams in Spokane County (refer to Table 6.2).

Table 6.2 Top Five Counties with Impaired Waterbodies[1] Due to Polychlorinated Biphenyls, State of Washington (2014)

County	Lakes	Large River	Marine	Rivers / Streams	Totals
Chelan	3	2	–	8	13
King	9	–	18	2	29
Pierce	2	–	13	–	15
Snohomish	4	–	3	2	9
Spokane	6	–	–	10	16
TOTALS	24	2	34	22	82

1 The numbers do not indicate unique bodies of water, rather they may include multiple assessments for sections of the same body of water. For example, Spokane River has 8 assessments listed for various reaches of the Spokane River.
(source: https://apps.ecology.wa.gov/ApprovedWQA, accessed August 1, 2019)

King, Pierce, and Spokane Counties account for nearly one-half of the population of the State of Washington (47.6%), according to the 2010 census data, and the five counties in Table 6.2 represent nearly sixty percent (59.2%) of the State of Washington population (State of Washington Office of Financial Management, 2018). These same five counties only represent approximately 15% (15.9%) of the acreage within the state (WA-List, 2015). This demonstrates that PCB contamination of the waterways in the State of Washington are correlated with the population. Population serves as a reasonable surrogate for PCB usage, and more generally, PCBs in the environment. This is because PCBs are associated with materials used to build and operate buildings and infrastructure, such as PCBs in caulk to seal building envelopes (open use), PCBs in hydraulic fluid (nominally closed use) and PCBs in transformers and capacitors to regulate electricity and lighting in buildings (closed use), as discussed in more detail in this report. As noted in the previous section of this report, PCBs are released to the environment during the use of PCB-containing materials, through accidental releases and spills, and during and after disposal. Generally, one would expect to see more PCB contamination in areas where PCB usage, handling, and/or disposal is higher, which is what is observed on a state-wide basis in the State of Washington.

The following figure highlights the waterbodies impacted by PCBs in the State of Washington.

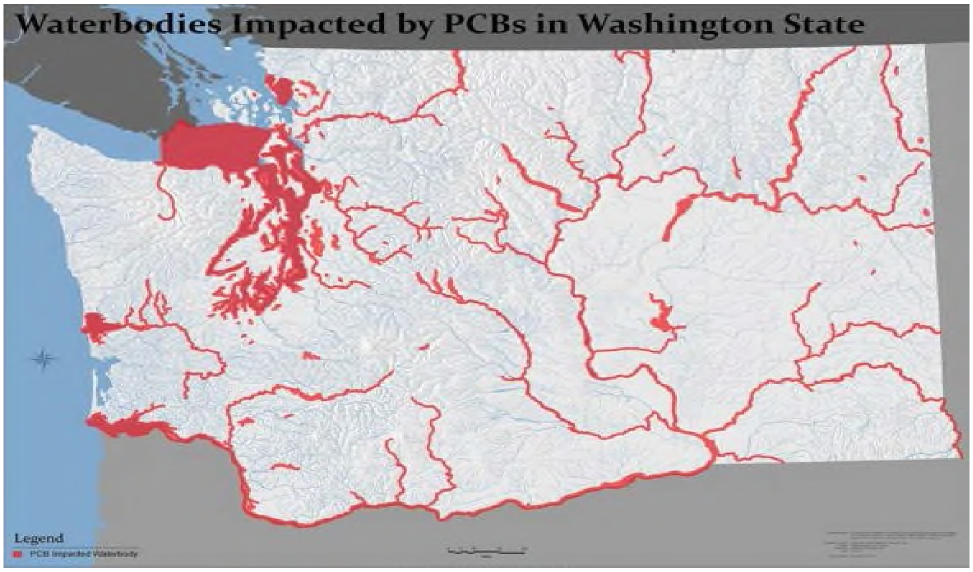

Figure 6.2 Map of PCB-impacted Waterways in the State of Washington (source: https://www.atg.wa.gov/news/news-releases/ag-ferguson-makes-washington-first-state-sue-monsanto-over-pcb-damages-cleanup, accessed August 2, 2019)

6.2.2 PCB Waste Sites

The State of Washington also has many hazardous waste sites with PCB contamination as a result of the use, accidental release and disposal of PCBs and products that contain PCBs. These PCBs are very likely attributable to Monsanto given that 99% of PCB consumption in the U.S. was directly linked to Monsanto-produced PCB products. Specifically, according the Department of Ecology, there were a total of 336 sites with confirmed or suspected PCB contamination when the Department prepared its PCB Chemical Action Plan in February 2015. The following table reproduces the waste site summary statistics from the Department's 2015 report. The total number of sites are greater than 336 as many sites have or had PCBs in multiple media. For example, the Department notes that, "[o]f the sites with confirmed or suspected PCBs in sediments, all but 15 also had soil with confirmed or suspected PCB contamination" (State of Washington Department of Ecology, 2015).

Table 6.3 Summary Statistics for Hazardous Waste Sites with Known or Suspected Polychlorinated Biphenyl Contamination, State of Washington (2015)

Medium	# of Sites	Confirmed	Suspected	Remediated	Below CUL
Soil	295	165	99	11	20
Groundwater	173	60	109	2	2
Sediment	62	47	11	1	3
Surface Water	89	19	64	6	0
Air	18	3	14	0	1

CUL Cleanup Level

Source: State of Washington Department of Ecology, PCB Chemical Action Plan, 2015

The following figure shows the distribution of the hazardous waste sites with PCB contamination in 2010, when there were 483 total sites of this kind around the state. Note the concentration of sites around the more populated areas, particularly in King and Pierce counties.

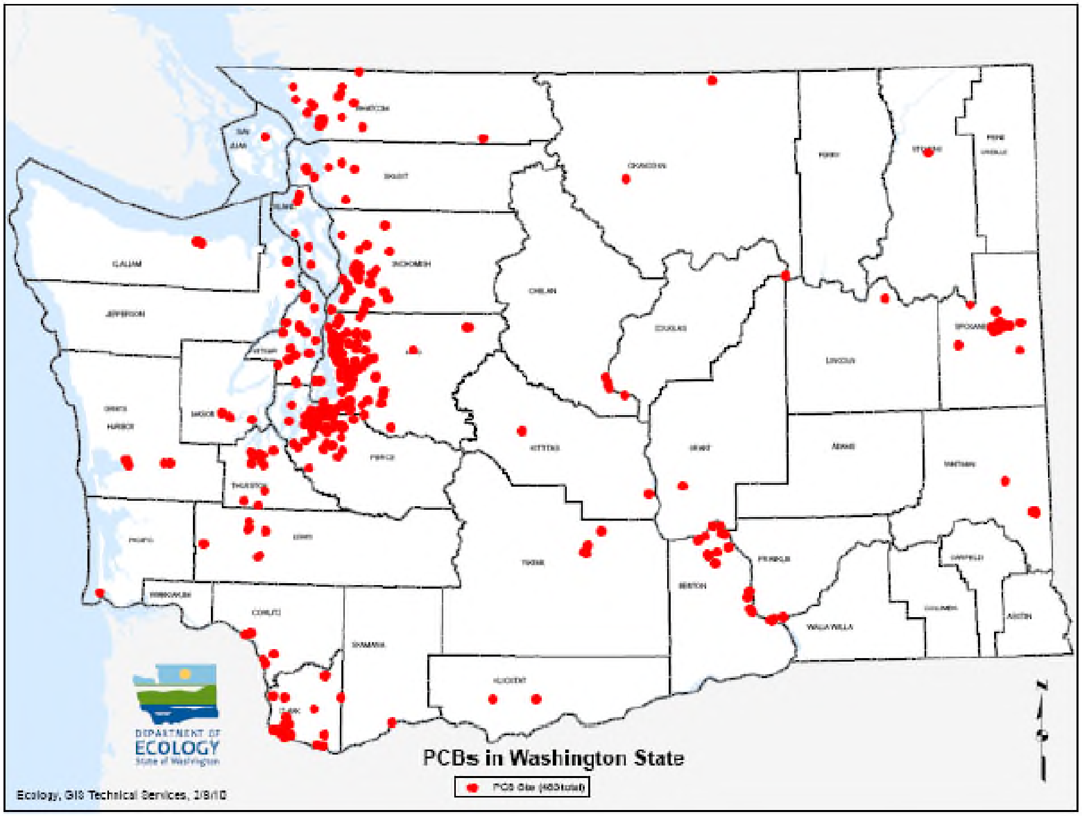

Figure 6.3 Map of Hazardous Waste Sites with PCB Contamination in the State of Washington as of 2010 (State of Washington Department of Ecology, 2015)

6.2.3 PCB Mass-balance and Monsanto's PCBs

According to Breivik, "population density is considered a suitable surrogate parameter" for estimating PCB consumption, given that PCBs are generally linked with use of electrical equipment (Breivik et al., 2002a). Moreover, several monitoring studies have demonstrated atmospheric levels of PCBs to be elevated in urban regions, e.g. (Hafner and Hits, 2003; Harner et al., 2004; Jaward et al., 2004). Scaled to Washington's population with respect to the U.S. population (~2.3%), the quantity of PCBs present in the environment of the State of Washington is estimated to be 3.6 million lbs, based on the results from the primary mass-balance model (U.S. Census Bureau, Accessed September 20, 2019a; Accessed September 20, 2019b). Monsanto PCBs likely account for at least 90% (3.2 million lbs out of 3.6 million lbs) of total PCBs released to the environment in the State of Washington.

Documentation produced by Monsanto on Aroclor use in the U.S. in 1968 was reviewed. According to this document, the State of Washington consumed five times the amount of Aroclor fluids for use as heat transfer and hydraulic applications (nominally closed uses) compared to Aroclors for use as a dielectric fluid (closed uses) (Monsanto Chemical Company, 1968). Nationally, this relationship is reversed. On average, five times the amount of Aroclors were used for dielectric applications versus heat transfer and hydraulic applications (Monsanto Chemical Company, 1968). This difference in fluid usage is very important from an environmental contamination perspective. Nominally closed applications were more likely to release PCBs to the environment by way of accidental releases and spills compared to closed uses, and likely contributed to the widespread contamination of the waterways in the State of Washington. According to the Breivik dynamic mass balance model, more than two times the proportion of PCBs used for nominally closed uses are released to the environment through accidental discharges and spills compared to closed uses (Breivik et al., 2007). In consideration of this fact, the 90% estimate or Monsanto's PCBs in the environment should be viewed as a minimum estimate, and the actual proportion of Monsanto's PCBs released to the environment is likely to be higher than this figure.

6.3 PCBS IN THE CITY OF SPOKANE

6.3.1 Impaired Waterbodies

As noted in Table 6.2 above, Spokane has 16 impaired waterbody sections due to the presence of PCBs. These include 10 river and stream reaches and 6 lake sections. In particular, the Spokane River has been the focus of recent investigation and remediation efforts. In 2012, the Spokane River Regional Toxics Task Force (SRRTTF) was formed, "by a Memorandum of Agreement (MOA), as required by permit conditions in the NPDES permits for the Washington Spokane River wastewater dischargers." The group comprises various stakeholders including the regulated community. The SRRTTF prepared a draft work plan in 2012 with the overarching goal, "to develop a comprehensive plan to bring the Spokane River into compliance with applicable water quality standards for PCBs" (Office of the City Clerk, 2012).

Figure 6.4 is reproduced from the LimnoTech report *2016 Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River* (LimnoTech, 2016). The land along the Spokane River is developed, while the land further away comprises forest and agricultural use. The proximity of the developed land to the Spokane River increases the likelihood of PCB contamination of the River given the presence of PCB-containing materials in the catchment area. These materials may include caulk, paint, hydraulic and heat transfer fluids and dielectric fluid in transformers and capacitors.

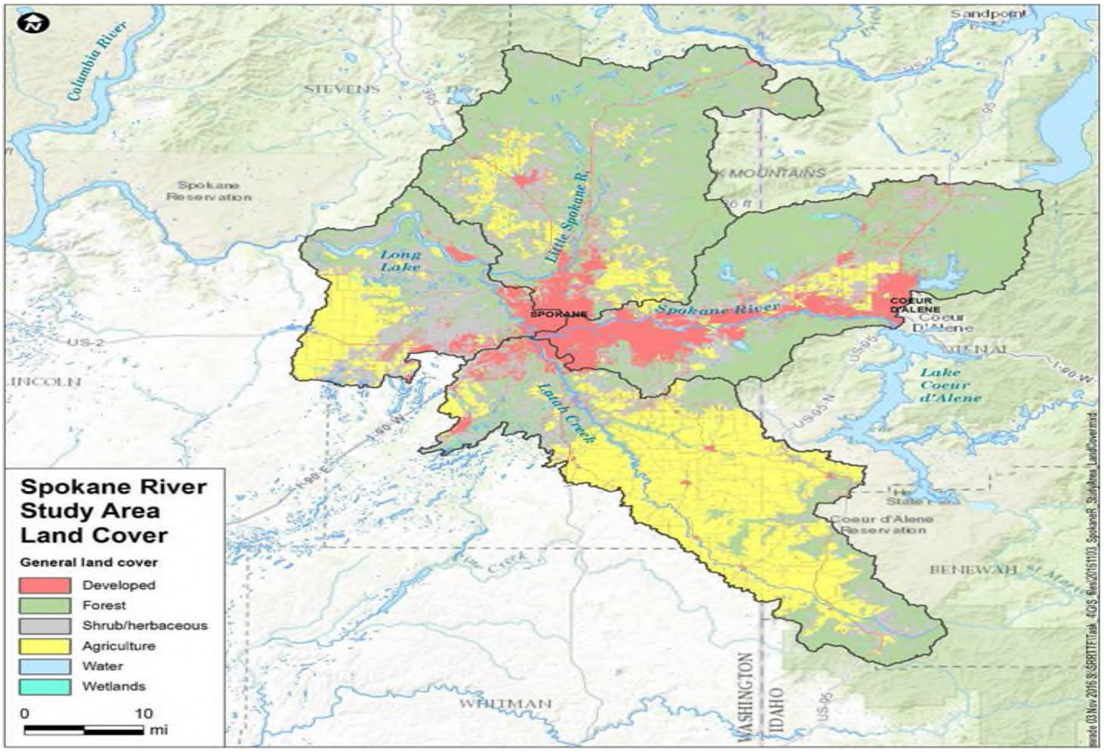

Figure 6.4 Map of Land Use in the Spokane Watershed, State of Washington (LimnoTech, 2016)

The SRRTTF summarized the available data from river water sampling programs (LimnoTech, 2016). A clear trend emerges from the data; the average PCB levels in the water column increases 3- to 4-fold beginning at the reach between the Mirabeau Point and Trent Bridge/Plante's Ferry (refer to Table 6.4). These areas correspond to the more heavily developed sections of the river catchment and include several industrial/municipal sources.

Table 6.4 Summary Statistics for Polychlorinated Biphenyls in the Water Column of the Spokane River, State of Washington (2014-2016)

River Reach	Concentration (pg/L)[1]			
	Minimum	Maximum	Geometric Mean	Arithmetic Mean
Lake Coeur d'Alene (SR-15)	3	72	14	17
Post Falls (SR-12)	NA	NA	18	21
Greenacres/Baker Road (SR-9)	19	32	14	24
Mirabeau Point (SR-8a)	33	44	18	37
Trent Bridge/Plante's Ferry (SR-7)	16	172	107	133
Greene Street Bridge (SR-4)	57	153	105	118
Spokane Gage (SR-3)	50	202	131	154
Nine Mile Dam (SR-1)	62	187	132	144

pg/L picograms per liter
NA not available

1 Minimum and maximum values may represent the lowest or highest average of two or more samples collected in a given timeframe, respectively.

Source: LimnoTech, 2016 Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River. 2016

The SRRTTF took a closer look at the sources of PCBs that could contribute to the levels found in the Spokane River and identified the following major source categories (refer to Table 6.5).

Table 6.5 Estimated Mass of Polychlorinated Biphenyls by Source Area Category, Spokane River, State of Washington

Source Area Category	PCB Mass (kg)
Legacy	
Building Sources	
Non-fixed[1]	50 – 40,000
Fixed[2]	60 – 130,000
Environmental	
Watershed soils	550 – 55,000
Subsurface soils – cleanup sites	Not currently estimated
Spokane River deep sediments	4 – 100
Lake Spokane deep sediments	8 – 200
Lake Spokane shallow sediments	0.4 – 10
Spokane River shallow sediments	0.06 – 0.15
Industrial equipment	6.4 – 25
Ongoing	
Inadvertent production	0.2 – 450
Environmental Source Areas Located outside the Study Area	
Lake Coeur d'Alene	~0 – 0.047
Atmospheric	Unknown

kg kilograms

1 PCBs in small capacitors in items such as appliances and lamp ballasts.
2 Building materials such as paints and sealants (e.g., caulks).

Source: LimnoTech, 2016, reproduced from Table 4 in the report.

As noted by the SRRTTF, “legacy PCBs in buildings (e.g., small capacitors, caulks) and legacy soil contamination are estimated to be the largest source areas of PCBs in the watershed” (LimnoTech, 2016). Legacy PCBs, in general, represent nearly all (greater than 99%) of the mass of PCB sources.

The SRRTTF also reviewed and estimated the PCB loadings to the River based on the type of discharges or delivery mechanisms (refer to Table 6.6). The load from the upstream sources is largely influenced by the volume of water discharged to the River by its source, Lake Coeur d’Alene. There is a significant contribution of PCBs to the River from groundwater loading, which is supported by the historic contamination of watershed soils as a significant source of legacy PCBs as noted in Table 6.5 and section 6.3.3 of this report.

Table 6.6 Estimated Polychlorinated Biphenyl Loadings by Delivery Mechanism

Delivery Mechanism	PCB Loading Rate (mg/day)
Upstream source (Lake Coeur d’Alene)	33 – 444
Groundwater loading	60 – 300
Tributaries	
Latah Creek	~0 – 215
Little Spokane River	15 – 200
WWTPs	
Total industrial	126 – 165
Total municipal	51 – 125
Idaho	4 – 10
Washington	47 – 115
MS4 stormwater/CSO	15 – 94
Bottom sediments	0.2 – 20
Fish hatcheries	Unknown
Atmospheric deposition to surface water	<0

PCB polychlorinated biphenyl
mg/day milligram per day
WWTPs waste water treatment plants
CSO combined sewer overflow

Source: LimnoTech, 2016, reproduced from Table 5 in the report.

6.3.2 Significant Discharges to the Spokane River

There are several industrial and municipal discharges along the River. Specifically, three discharges are highlighted in the SRRTTF report: (i) Kaiser Trentwood facility, (ii) Inland Empire Paper and (iii) the City of Spokane wastewater treatment facility (LimnoTech, 2016). Other municipal discharges are listed and include: Spokane County, Coeur d’Alene in Idaho, Post Falls, Idaho, Liberty Lake, and Hayden Area Regional Sewer Board. However, these discharges are relatively minor contributors to PCB loadings in the River as shown in Table 7 of the SRRTTF report (LimnoTech, 2016).

The Kaiser Trentwood facility, located just southeast and upstream of Plante's Ferry, manufactured rolled aluminum products, mostly for the aerospace industry as well as other engineering applications (State of Washington Department of Ecology, Accessed September 20, 2019). Aluminum production is an energy and heat intensive operation. Historically, Aroclors were a necessary part of this production process to distribute and control the electrical power requirements and to provide heat-stable, non-flammable liquids for heat transfer applications. As such, the presence of PCBs in and around this facility is not surprising. The Kaiser facility is listed with the Department of Ecology as a contaminated site specifically for PCBs above clean up levels in the soil and groundwater and for PCBs that may be above clean up levels in the surface water (State of Washington Department of Ecology, Accessed September 20, 2019).[60] An analysis by Lisa Rodenburg, Ph.D., of samples of the groundwater at the Kaiser facility found that "virtually all of the PCBs detected" were commercial, or legacy PCBs (Rodenburg, 2019). Dr. Rodenburg also analyzed water samples collected from the outfall at Kaiser and determined that "98% of the total PCBs" were commercial PCBs.

Inland Empire Paper Company is a paper recycling facility located just west and downstream of Trent Bridge. The primary source of PCBs from this facility is believed to be related to the inks and dyes in the paper and print materials that are recycled. The PCB source identification work identified the dyes and inks as the primary contributor to the PCBs found in the waste water (Ecology, 2019). However, the laboratory reported Aroclor mixtures in the samples including A1242, A1254 and 1260. Notably, PCB-11, a congener known to be associated with diarylide pigments was not the primary congener identified. The relative contribution of this signature congener was generally between 2.5% and 38% of the total PCBs, with most samples containing less than 20% PCB-11 relative to total PCBs (Ecology, 2019). The presence of what appears to be Aroclor mixtures in the samples and the relatively low abundance of PCB-11 in most of the samples suggests that legacy PCBs may be a significant source of PCBs found in the wastewater from Inland. Dr. Rodenburg found that, "commercial PCBs comprised more than 80% of the total PCBs on average" identified in the water samples collected from the Inland Empire Paper wastewater treatment facility by Lisa Rodenburg, Ph.D. (Rodenburg, 2019).

City of Spokane Riverside Park Advanced WWTP process the majority of wastewater from the City of Spokane and discharges the treated wastewater to the River between the Monroe Street and Nine Mile Dams. The system serves over 240,000 individuals who live and/or work in the City of Spokane. The system processes just under 30 million gallons of wastewater per day, on average, with maximum daily flow between 50 and 60 million gallons per day. The system has both dedicated sanitary sewer and a combined storm and sanitary sewer, with one discharge for the treated effluent, one discharge for the untreated or partially treated effluent, and many combined sewer outflow points (Ecology, 2019).

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[60] Kaiser facility cleanup site ID 7093.

The Cithof Spokane WWTP treats waste water from the following significant industrial users: (i) ALSCO-Steiner Corp (industrial laundry and garment rentals), (ii) Associated Painters (stripping, etching and aircraft paint), (iii) Darigold Spokane (manufacturer and packager of dairy and fruit juices), (iv) EZ Loader boat trailers (trailer manufacturer and coating application), (v) Fairchild Air Force Base (aircraft and ground vehicle maintenance), (vi) Global Metal Technologies (ore processing), (vii) Goodrich Spokane UTC – Aerospace Systems (specialty carbon brake pads for aircraft), (viii) Johanna Beverages (blender and bottler of citrus beverages), (ix) Jubilant-Hollister-Stier Laboratories (pharmaceuticals), (x) Providence Sacred Heart Laundry (commercial laundry for healthcare), (xi) Spokane County Mica Landfill (leachate from landfill), (xii) Spokane Metal Finishing (metals) and (xiii) Triumph Composite Systems (composite aircraft ducts and panels).

To satisfy the conditions of its NPDES permit, the City of Spokane undertook and evaluation of the potential sources of PCBs in its wastewater. They tested a number of products that were regularly used by the City and that could come into contact with stormwater. They also tested common household items, such as soaps, detergents and toothpaste that would be found in the wastewater. Most of the materials tested contained less than 1 part per billion (ppb) of PCBs. Some products, including paints, plastic liners, thermoplastic road tape, crack sealer, pesticide and dust suppressant, were found to contain PCBs between 1 and 65 ppb. One product, hydroseed, was found to contain 2,500 ppb of PCBs, a very high level. However, additional testing of similar products could not replicate this result (<2 ppb), indicating that this result may be anomalous and due to contamination or an artifact in the sample (City of Spokane, 2017).

The City also analyzed the PCB congeners found in the samples. They determined that the best fit for the data was a "linear combination of 11% Aroclor 1242, 12% Aroclor 1248, 50% Aroclor 1254, and 27% Aroclor 1260." They also noted that, "[t]he only significant congener that is not accounted by Aroclors is PCB-11, representing approximately 2% of the influent mass of PCBs." (City of Spokane, 2017). This suggests that pigments (and the PCBs that may be contained therein) are not significantly impacting the effluent that is discharged into the River by the City of Spokane. Analysis conducted by Dr. Rodenburg found that commercial PCBs in water samples from the combined sewer overflows made up about 95% of the mass of PCBs, while commercial PCBs found in samples of the treated effluent from the City of Spokane's WWTP comprised more than 90% of the total PCBs found on average (Rodenburg, 2019).

6.3.3 PCB Waste Sites

A search of EPA's National Priorities List (NPL), a database of hazardous waste sites that require clean up, found two other sites near the Spokane River in addition to the Kaiser site that were impacted by legacy PCBs.

The Spokane Junkyard and related properties (EPA ID# WAD981767296) is a 16-acre light commercial and residential site located in the Hillyard area of Spokane. The site operated as a junkyard from the 1940s until 1983 and “accepted military surplus items, automobiles, heavy equipment, appliances and electrical transformers.” Adjacent to the site was Spokane Metals Co., “who recycled scrap metal, including transformers and batteries, from 1936 to 1983” (USEPA, Accessed September 20, 2019). Together the junkyard and recycling activities contaminated soils with polychlorinated biphenyls (PCBs) and created a reservoir of PCBs for other environmental media, such as groundwater.

Listed in the NPL in June 1994, three of the site generators, Kaiser Aluminum, Avista, and Inland Power and Light completed a site investigation in 1995. The site remediation included developing a cell on the old Spokane Metals site where 10,000 tons of PCB and lead contaminated soil were secured (USEPA, Accessed September 20, 2019).

The second listed site is the old Spokane Apparatus Service Shop operated by General Electric from 1961 until 1980. Transformers and electric-related equipment were cleaned and repaired on the site, and transformer oils were stored there as well. According to the EPA, “[s]ome of the equipment and transformers contained polychlorinated biphenyls (PCBs), which were released into a dry well during steam cleaning. These activities contaminated soil, groundwater and sludge with PCBs.” Following cleanup, operation and maintenance activities and monitoring are ongoing (USEPA, Accessed September 20, 2019).

6.3.4 PCB Mass-balance and Monsanto’s PCBs

Scaled to the City of Spokane’s population with respect to the State of Washington (~2.9%), the quantity of PCBs present in the environment of the City of Spokane is approximately 100,000 lbs., based on the results from the primary mass-balance model (U.S. Census Bureau, Accessed September 20, 2019a). Monsanto PCBs likely account for 90% (90,000 lbs out of 100,000 lbs) of total PCBs released to the environment in the City of Spokane, Washington.

In addition to utilizing the results of the mass-balance model, this evaluation also reviewed information produced from studies and local organizations to assess PCB contamination in Spokane. Multiple studies have been conducted to assess PCB loading sources or source areas associated with Spokane’s watershed. Source areas are places where PCBs were used, inadvertently released, systematically discarded, or accumulated (LimnoTech, 2016). The source areas in Spokane are described as three categories: 1) legacy PCB source areas currently present in the watershed; 2) ongoing PCB source areas continually intruding to the watershed through inadvertent inclusion in commercial products; and 3) environmental transport of non-local PCBs into the watershed (LimnoTech, 2016). As displayed in Table 6.5, the most significant source area category is estimated to be legacy, with the majority of PCBs contained in fixed building materials such as paint and sealants, contaminated watershed soils, and non-fixed building

sources such as small capacitors (LimnoTech, 2016). These estimated values were developed based on information obtained from peer-reviewed literature, environmental measurements in Spokane and Spokane-specific industry data. The estimated contribution of inadvertently produced PCBs ranges from 0.2 to 450 kg/yr. According to these values, the contribution of inadvertent PCBs in comparison to legacy PCBs ranges from 0.03% to 0.2% (LimnoTech, 2016).

A complementary approach to the general mass balance calculation is provided to address some of the unique circumstances in Spokane. This analysis relied on the data provided by the SRRTTF regarding PCB river loading estimates (refer to Table 6.6). Specifically, the mid-point was selected for each of the range of values provided by the SRRTTF (LimnoTech, 2016). To further refine the estimates for the major dischargers, Table 7 in the LimnoTech 2016 report was consulted. Then, discounts were applied to these loading values to calculate the relative contribution of legacy and non-legacy PCBs (e.g., inadvertently generated, globally cycled) for each delivery mechanism to the River on a percent basis, similar to the mass-balance approach discussed above. The discount multipliers were derived from the Expert Report of Lisa A. Rodenburg, Ph.D. (Rodenburg, 2019). Specifically, Dr. Rodenburg estimated the attribution of legacy and non-legacy PCBs in the Spokane River using a combination of Positive Matrix Factorization and Multiple Linear Regression techniques on actual data collected from the River and effluents. The discount multipliers applied to the loading data represent the estimated percentage of non-legacy PCBs found in the samples, and, therefore, likely not to be associated with Monsanto. The following table outlines this approach.

Table 6.7 Estimated Monsanto-Produced Legacy Polychlorinated Biphenyls in the Spokane River Environment, State of Washington

PCB Delivery Mechanism	Total Loading Estimate (mg/day)[1]	Discount Multiplier for Non-Legacy PCBs[2]	Estimated non-Legacy PCBs (mg/day)	Estimated Legacy PCBs (mg/day)
Upstream	239	0.10	24	220
Groundwater	180	0.010	1.8	180
Tributaries	215	0.10	22	190
Kaiser	69	0.10	6.9	62
Inland Paper	76	.20	15	61
Municipal	88	0.10	8.8	79
Combined Sewer and Stormwater	55	0.050	2.8	52
Bottom sediments	10	0.050	0.50	9.5
TOTALS	932		82	850
% of Total Loading	100%		8.8%	91%

PCB polychlorinated biphenyl
mg/day milligrams per day

1 From Tables 5 and 7 in the LimnoTech 2016 Report, values are approximate mid-points between reported ranges.
2 Multipliers are based on the Export Report of Lisa A. Rodenburg, Ph.D. Prepared for the City of Spokane v. Monsanto Company, et. al. dated October 11, 2019, where the multiplier is calculated as follows: (1 - (% Aroclor in samples/100)).

Source: LimnoTech, 2016 Comprehensive Plan to Reduce Polychlorinated Biphenyls (PCBs) in the Spokane River. 2016

Table 6.7 demonstrates that Monsanto's PCBs in the environment are estimated at 91%, virtually identical to the mass-balance estimate of 90%.

The impairment status for the Spokane River is due to the level of PCBs found in river fish (LimnoTech, 2016).[61] Notably, Dr. Rodenburg found that legacy or "commercial PCBs account for virtually all of the PCBs detected" in the fish tissue samples.[62] Therefore, the impairment status of the Spokane River as it relates to concentrations of PCBs in the river is nearly exclusively due to Monsanto's legacy PCBs.

61 LimnoTech, 2016, p. 11.
62 Rodenburg, 2019, p. 3.

7.0 CONCLUSIONS

The following summarizes my opinions regarding the attribution of Monsanto PCBs in the environment of the U.S., the State of Washington, and the City of Spokane.

1. Monsanto was responsible for just over one-half of the global PCB production from the mid-1930s through the present time (see section 3.0).
2. Monsanto produced nearly all (99%) of the PCBs consumed in the U.S. (see section 3.1).
3. Approximately 150 million pounds of PCBs have been released and are free in the environment of the U.S. (see section 5.3).
4. Monsanto's PCBs are the dominant source of PCBs in the U.S. environment (see section 6.1).
5. Other potential non-Monsanto sources in the U.S. environment are inadvertently-generated PCBs and PCBs that cycle globally. Generally, these PCBs make up approximately <1% to 10% of the total PCBs free in the environment (see sections 3.4, 5.2 and 6.0).
6. Using a dynamic mass-balance model and considering other potential non-Monsanto sources of PCBs, I estimate that approximately 90% of PCBs in the environment are attributable to Monsanto. This may be understated as the inputs to the model generally favored an increase in the quantity of non-Monsanto PCBs in the U.S. environment (see section 6.1).
7. In the State of Washington, Monsanto's PCBs are expected to comprise at least 90% of the PCBs in the environment as the State of Washington used a much higher proportion of PCBs for nominally closed uses, which results in a higher proportion of PCBs released from accidental spills and discharges compared to closed uses (see section 6.2.3).
8. In Spokane, work by Dr. Rodenburg found that approximately 91% of PCBs found in the Spokane River environment are likely attributable to Monsanto, confirming the results of the dynamic mass-balance model (see section 6.3.4).
9. Considering these facts, an overwhelming majority of PCBs in the environment in the U.S., the State of Washington and the City of Spokane are directly attributable to Monsanto.
10. Given the facts and analysis presented in this report, I agree with Monsanto's assessment that, "Monsanto is most probably responsible for the U.S. contamination" (see section 6.0). I also agree with Monsanto's characterization of inadvertently generated PCBs as nothing more than a "PCB footnote" and a "genuine molehill" in comparison to the quantities of legacy PCBs released to the environment (see section 3.4).

A mass balance approach was used to estimate the PCB burden in the U.S. environment and to attribute the proportion of environmental PCBs that are likely to be associated with Monsanto's production of this class of chemicals. Models published in the peer-reviewed scientific literature

were relied upon to assign emission factors to production numbers in order to estimate the quantity of PCBs released into the environment. The environmental burden of PCBs was adjusted to account for imports, exports, inadvertent production of PCBs, and the movement of PCBs both into and out of the U.S. environment due to global cycling phenomena.

Based on this analysis, Monsanto PCBs account for 90% (140.1 out of 155.5 million lbs) of total PCBs released to the U.S. environment. The overall range of PCBs in the U.S. environment likely attributable to Monsanto is 83.2% to 93.8%. The percentages are likely an underestimate for several reasons, including: (i) all PCBs leaving the U.S. environment by global cycling were assumed to be Monsanto PCBs thereby reducing the environmental load of Monsanto's PCBs in the U.S.; (ii) all PCBs entering the U.S. environment were assumed to be PCBs that did not originate from Monsanto; and (iii) the model assumed that 100% of the inadvertent PCBs (non-Monsanto PCBs) were released into the U.S. environment.

The model of the U.S. PCB burden in the environment described above was indexed to population to determine the environmental burden of PCBs in the State of Washington. Scaling production, use, and emission values using census data, Monsanto's PCBs account for 90% (3.2 million lbs out of 3.6 million lbs) of total PCBs released into the environment in the State of Washington.

Lastly, the national values were scaled to the City of Spokane in much the same way that is was done for the State of Washington. Based on this analysis, Monsanto's PCBs account for 90% (90,000 lbs out of 100,000 lbs) of total PCBs released to the environment in the City of Spokane. A factor analysis conducted by Dr. Rodenburg identified relative proportions of Aroclor (commercial PCBs) and non-Aroclor PCBs in samples collected from the Spokane River environment. When these results are applied to estimated loadings of PCBs to the Spokane River, approximately 91% of the PCBs that enter the Spokane River environment are Monsanto's PCBs. The concordance of these two independent assessments (mass-balance model and Dr. Rodenburg analysis) further strengthen the conclusion that the vast majority of PCBs found in the State of Washington and the City of Spokane are attributable to Monsanto.

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APPENDIX A

Table A.1 Mass-Balance Lower- and Upper-bound Sensitivity Analysis Models

Input	**Primary Mass-Balance Model:** Emission factor 11.8% for Monsanto, Geneva, & Imported PCBs. Emission factor 100% for Inadvertent PCBs. Production, Export, & Import values based on best estimates.	**Mass-Balance Model 1:** Emission factor 11.8% for Monsanto, Geneva, Imported, & Inadvertent PCBs. Production, Export, & Import values based on best estimates.	**Mass-Balance Model 2:** Emission factor 1.29% for Monsanto, Geneva, Imported, & Inadvertent PCBs. Production, Export, & Import values based on best estimates.
Global Production (million lbs)	2,990	2,990	2,990
U.S. Production (million lbs)	1,401	1,401	1,401
Monsanto Production (million lbs)	1,400	1,400	1,400
Geneva Industries Production (million lbs)	1	1	1
Exported from U.S. (million lbs)	150	150	150
Imported to U.S. (million lbs)	3	3	3
Total PCB Consumption in U.S. (million lbs)	1,254	1,254	1,254
Monsanto PCB Consumption in U.S. (million lbs)	1,250	1,250	1,250
Release to U.S. Environment Based on Consumption (excluding inadvertent PCBs) (million lbs)	148.0	148.0	16.2
Monsanto Release to U.S. Environment Based on Consumption (million lbs)	147.5	147.5	16.1
Inadvertent PCB Release to U.S. Environment Based on Production (million lbs)	5.5	0.7	0.07
Global Cycling of International PCBs into U.S. (million lbs)	9.4	9.4	1.0
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	-7.4	-7.4	-0.8
Monsanto PCB Release to the Environment U.S. (million lbs)	140.1	140.1	15.3
Total PCB Release to the Environment U.S. (million lbs)	155.5	150.6	16.5
PCBs Attributable to Monsanto in U.S. Environment (percent %)	90.1%	93.0%	93.0%

PCBs polychlorinated biphenyls
lbs pounds

Table A.1 Mass-Balance Lower- and Upper-bound Sensitivity Analysis Models [Continued]

Input	Mass-Balance Model 3:	Mass-Balance Model 4:	Mass-Balance Model 5:	Mass-Balance Model 6:
	Emission factor 11.8% for Monsanto, Geneva, Imported, & Inadvertent PCBs.			
	Production, Export, & Import values based on low estimates.	Production values based on low estimates. Export & Import values based on high estimates.	Production & Export values based on low estimates. Import value based on high estimates.	Production & Import values based on low estimates. Export value based on high estimates.
Global Production (million lbs)	2,990	2,990	2,990	2,990
U.S. Production (million lbs)	1,121	1,121	1,121	1,121
Monsanto Production (million lbs)	1,120	1,120	1,120	1,120
Geneva Industries Production (million lbs)	1	1	1	1
Exported from U.S. (million lbs)	120	180	120	180
Imported to U.S. (million lbs)	2.1	3.9	3.9	2.1
Total PCB Consumption in U.S. (million lbs)	1,003.1	944.9	1,004.9	943.1
Monsanto PCB Consumption in U.S. (million lbs)	1,000.0	940.0	1,000.0	940.0
Release to U.S. Environment Based on Consumption (excluding inadvertent PCBs) (million lbs)	118.4	111.5	118.6	111.3
Monsanto Release to U.S. Environment Based on Consumption (million lbs)	118.0	110.9	118.0	110.9
Inadvertent PCB Release to U.S. Environment Based on Production (million lbs)	0.6	0.6	0.6	0.6
Global Cycling of International PCBs into U.S. (million lbs)	11.0	11.0	11.0	11.0
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	-5.9	-5.5	-5.9	-5.5
Monsanto PCB Release to the Environment U.S. (million lbs)	112.1	105.4	112.1	105.4
Total PCB Release to the Environment U.S. (million lbs)	124.1	117.6	124.3	117.4
PCBs Attributable to Monsanto in U.S. Environment (percent %)	90.3%	89.6%	90.2%	89.8%

PCB polychlorinated biphenyl
lbs pounds

Table A.1 Mass-Balance Lower- and Upper-bound Sensitivity Analysis Models [Continued]

Input	Mass-Balance Model 7:	Mass-Balance Model 8:	Mass-Balance Model 9:	Mass-Balance Model 10:
	Emission factor 11.8% for Monsanto, Geneva, Imported, & Inadvertent PCBs.			
	Production values based on high estimates. Import & Export values based on low estimates.	Production, Import, & Export values based on high estimates.	Production & Import values based on high estimates. Export value based on low estimates.	Production & Export values based on high estimates. Import value based on low estimates.
Global Production (million lbs)	2,990	2,990	2,990	2,990
U.S. Production (million lbs)	1,471	1,471	1,471	1,471
Monsanto Production (million lbs)	1,470	1,470	1,470	1,470
Geneva Industries Production (million lbs)	1	1	1	1
Exported from U.S. (million lbs)	120	180	120	180
Imported to U.S. (million lbs)	2.1	3.9	3.9	2.1
Total PCB Consumption in U.S. (million lbs)	1,353.1	1,294.9	1,354.9	1,293.1
Monsanto PCB Consumption in U.S. (million lbs)	1,350.0	1,290.0	1,350.0	1,290.0
Release to U.S. Environment Based on Consumption (excluding inadvertent PCBs) (million lbs)	159.7	152.8	159.9	152.6
Monsanto Release to U.S. Environment Based on Consumption (million lbs)	159.3	152.2	159.3	152.2
Inadvertent PCB Release to U.S. Environment Based on Production (million lbs)	0.6	0.6	0.6	0.6
Global Cycling of International PCBs into U.S. (million lbs)	8.9	8.9	8.9	8.9
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	-8.0	-7.6	-8.0	-7.6
Monsanto PCB Release to the Environment U.S. (million lbs)	151.3	144.6	151.3	144.6
Total PCB Release to the Environment U.S. (million lbs)	161.3	154.8	161.5	154.6
PCBs Attributable to Monsanto in U.S. Environment (percent %)	93.8%	93.4%	93.7%	93.6%

PCB polychlorinated biphenyl
lbs pounds

Table A.1 Mass-Balance Lower- and Upper-bound Sensitivity Analysis Models [Continued]

Input	Mass-Balance Model 11:	Mass-Balance Model 12:	Mass-Balance Model 13:	Mass-Balance Model 14:
	Emission factor 11.8% for Monsanto, Geneva, & Imported PCBs and an emission factor 100% for Inadvertent PCBs.			
	Production, Export, & Import values based on low estimates.	Production values based on low estimates. Export & Import values based on high estimates.	Production & Export values based on low estimates. Import value based on high estimates.	Production & Import values based on low estimates. Export value based on high estimates.
Global Production (million lbs)	2990	2990	2990	2990
U.S. Production (million lbs)	1121	1121	1121	1121
Monsanto Production (million lbs)	1120	1120	1120	1120
Geneva Industries Production (million lbs)	1	1	1	1
Exported from U.S. (million lbs)	120	180	120	180
Imported to U.S. (million lbs)	2.1	3.9	3.9	2.1
Total PCB Consumption in U.S. (million lbs)	1003.1	944.9	1004.9	943.1
Monsanto PCB Consumption in U.S. (million lbs)	1000.0	940.0	1000.0	940.0
Release to U.S. Environment Based on Consumption (excluding inadvertent PCBs) (million lbs)	118.4	111.5	118.6	111.3
Monsanto Release to U.S. Environment Based on Consumption (million lbs)	118.0	110.9	118.0	110.9
Inadvertent PCB Release to U.S. Environment Based on Production (million lbs)	5.5	5.5	5.5	5.5
Global Cycling of International PCBs into U.S. (million lbs)	11.0	11.0	11.0	11.0
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	-5.9	-5.5	-5.9	-5.5
Monsanto PCB Release to the Environment U.S. (million lbs)	112.1	105.4	112.1	105.4
Total PCB Release to the Environment U.S. (million lbs)	129.0	122.5	129.2	122.3
PCBs Attributable to Monsanto in U.S. Environment (percent %)	86.9%	86.1%	86.8%	86.2%

PCB polychlorinated biphenyl
lbs pounds

Table A.1 Mass-Balance Lower- and Upper-bound Sensitivity Analysis Models [Continued]

Input	Mass-Balance Model 15:	Mass-Balance Model 16:	Mass-Balance Model 17:	Mass-Balance Model 18:
	Emission factor 11.8% for Monsanto, Geneva, & Imported PCBs and an emission factor 100% for Inadvertent PCBs.			
	Production values based on high estimates. Export & Import values based on low estimates.	Production, Export, & Import values based on high estimates.	Production & Import values based on high estimates. Export value based on low estimates	Production & Export values based on high estimates. Import value based on low estimates.
Global Production (million lbs)	2,990	2,990	2,990	2,990
U.S. Production (million lbs)	1,471	1,471	1,471	1,471
Monsanto Production (million lbs)	1,470	1,470	1,470	1,470
Geneva Industries Production (million lbs)	1	1	1	1
Exported from U.S. (million lbs)	120	180	120	180
Imported to U.S. (million lbs)	2.1	3.9	3.9	2.1
Total PCB Consumption in U.S. (million lbs)	1,353.1	1,294.9	1,354.9	1,293.1
Monsanto PCB Consumption in U.S. (million lbs)	1,350.0	1,290.0	1,350.0	1,290.0
Release to U.S. Environment Based on Consumption (excluding inadvertent PCBs) (million lbs)	159.7	152.8	159.9	152.6
Monsanto Release to U.S. Environment Based on Consumption (million lbs)	159.3	152.2	159.3	152.2
Inadvertent PCB Release to U.S. Environment Based on Production (million lbs)	5.5	5.5	5.5	5.5
Global Cycling of International PCBs into U.S. (million lbs)	8.9	8.9	8.9	8.9
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	-8.0	-7.6	-8.0	-7.6
Monsanto PCB Release to the Environment U.S. (million lbs)	151.3	144.6	151.3	144.6
Total PCB Release to the Environment U.S. (million lbs)	166.2	159.6	166.4	159.4
PCBs Attributable to Monsanto in U.S. Environment (percent %)	91.1%	90.6%	91.0%	90.7%

PCB polychlorinated biphenyl
lbs pounds

APPENDIX B

Table B.1 Mass-Balance Monte Carlo Sensitivity Analysis Model

Input Parameter	Minimum	Maximum	Mode	Distribution	Reference
Monsanto Production (million lbs)	1120	1470	1400	Triangular	Durfee, 1976
Geneva Industries Production (million lbs)	1	1	1	_	Durfee, 1976
Inadvertent Production (million lbs)	5.5	5.5	5.5	_	Chemical Manufacturers Association Special Programs Panel on PCBs, 1981 Environmental Defense Fund et al., 1983 Guo et al., 2014
Exported from U.S. (million lbs)	120	225	150	Triangular	Durfee, 1976
Imported to U.S. (million lbs)	2.1	3.9	3	Triangular	Durfee, 1976
Emission Factor of Legacy PCBs Environment	0.083	0.118	0.153	Triangular	Breivik et al., 2007 Durfee, 1976
Emission Factor of Inadvertent PCBs Environment	0.01	.34	1	Triangular	Breivik et al., 2007 Environmental Defense Fund et al., 1983
Global Cycling of International PCBs into U.S. (million lbs)	0.05	0.1	_	Uniform	Wania and Su, 2004
Global Cycling of Monsanto PCBs out of U.S. (million lbs)	0.05	0.1	_	Uniform	Wania and Su, 2004

million lbs million pounds

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APPENDIX C

KEVIN M. COGHLAN, M.S., C.I.H., QUALIFICATIONS AND CURRICULUM VITAE

My name is Kevin Michael Coghlan. I am a Principal Scientist and Chief Operating Officer at Environmental Health & Engineering, Inc. ("EH&E"), a firm that provides environmental, health, safety, and engineering assessment and management services related to human health and the built environment. I am resident in the firm's Massachusetts office. My business address is 180 Wells Avenue, Newton, Massachusetts 02459.

I have over 30 years of broad-based experience in assessing, evaluating, characterizing, and solving environmental problems. I have personally managed and directed over several hundred indoor environmental investigations in a variety of work settings, including education, healthcare, commercial office, laboratory and research, medical appliance manufacturing and light industrial environments. I have extensive experience in identifying and remediating various environmental hazards, including polychlorinated biphenyls (PCBs) as well as other toxic and/or hazardous substances and/or compounds such as asbestos, heavy metals, semi-volatile organic compounds, volatile organic compounds, pesticides, fibers, microbiologicals, and noise.

I was awarded a Bachelor of Science degree in biology from Fairfield University in Fairfield, Connecticut in 1987 and a Master of Science in Industrial Hygiene from the Francis College of Engineering at the University of Massachusetts Lowell, located in Lowell, Massachusetts in 1993. This program has held accreditation by the Accreditation Board for Engineering and Technology's (ABET) Applied Science Accreditation Commission since 1992. Upon graduation in my final year, I received an Outstanding Graduate Student Award from the University's Department of Work Environment.

From 1987 to 1989, I worked as Field Operations Supervisor at Hygenix Inc. where I provided hazardous materials assessment services.

From 1989 to 1993, I was an Industrial Hygiene Technologist at the Massachusetts Institute of Technology. During that time, I also provided training in Industrial Hygiene and Hazardous Materials through an independent training company and the New England Laborer's Union. I provided Occupational Health and Safety training to members of New England Laborer's Union regarding hazardous materials abatement.

Since 1993, I have been a Diplomate of the American Board of Industrial Hygiene certified in the comprehensive practice of Industrial Hygiene. I first joined EH&E in 1993 as a Staff Scientist. In 1994, I was promoted to a Senior Associate providing project leadership in technical work approach, and from 1996 to 2003, I became a Technical Director overseeing the company's technical approach and quality control program and promoted to the position of Principal

Scientist. From 2004 to 2005, I became Director of Operations responsible for managing EH&S technical operations and service delivery. From 2005 to 2014, I assumed the role of Director of EH&S Compliance and Strategic Support, as well as being Chief Operating Officer (to which role I was promoted in 2008 and continue to perform).

My present responsibilities include directing the company's technical operations, organizational management, and monitoring financial and operational performance, in addition to providing technical consulting services to our client base.

In my technical capacity, I have designed and implemented environmental sampling and assessment programs for hundreds of building and environmental sites for various contaminants, including PCBs, volatile organic compounds, asbestos, particulates, polyaromatic hydrocarbons, and metals. The environmental assessment work has included establishing and validating data quality objectives for the programs. Field work has also included determining emission rates for various environmental contaminants for use in exposure modeling scenarios, including the use of dynamic mass balance models to estimate contaminant levels under various exposure scenarios.

I have, over the years, had extensive experience with PCBs, including scientific modeling in relation to the fate and transport of PCBs in the man-made (i.e., buildings) and natural environments. Beginning about December, 2000 until about 2004, I was the Principal Investigator and Project Manager for one of the largest, most comprehensive indoor environmental exposure assessment for PCBs from building materials, in which the U.S. Environmental Protection Agency ("EPA") was involved. As part of my responsibilities on this project, I, amongst other things: (i) quantified airborne and surface concentrations for PCBs, (ii) characterized and apportioned sources of PCBs in indoor air, on surface and in construction materials for both risk assessment and mitigation purposes, (iii) worked with local and nationally-recognized environmental health professionals, (iv) monitored occupants' biological PCB exposure by reference to blood sampling, and (v) performed an epidemiological review for cancer mortality working with a team of health experts from Boston University School of Public Health and the Rhode Island Cancer Registry.

In or about October 2011, I was also a Peer Reviewer for the EPA in relation to Part I of Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings ("2011 EPA PCB Study"). Part 1 of the 2011 EPA PCB Study involved the characterization of PCB emissions from PCB- containing building products, such as caulk and lighting ballasts ("2011 EPA Study 1").

I have personally been involved in, or directed, over thirty projects involving the identification, assessment, remediation, risk assessment and risk communications for PCB-containing building materials, such as caulk and paint, representing nearly 10 person-years of direct scientific effort

to complete this work. I have published papers in scientific proceedings and the professional literature that are specific to identification, assessment and mitigation of PCBs, and I participated in an expert panel regarding PCBs in construction materials at the American Industrial Hygiene Association Conference and Exposition in Montreal, Canada in May, 2013. A full copy of my curriculum vitae which gives full details of my professional qualifications and publications is attached.

KEVIN M. COGHLAN, M.S., C.I.H.

PRINCIPAL SCIENTIST/CHIEF OPERATING OFFICER

BACKGROUND SUMMARY

2008 –	Chief Operating Officer and Principal Scientist, Environmental Health & Engineering, Inc.
2005 – 2014	Director, EH&S Compliance and Strategic Support and Principal Scientist, Environmental Health & Engineering, Inc.
2004 – 2005	Director of Operations and Principal Scientist, Environmental Health & Engineering, Inc.
1996 – 2003	Technical Director and Principal Scientist, Environmental Health & Engineering, Inc.
1994 – 1995	Senior Associate/Industrial Hygienist, Environmental Health & Engineering, Inc.
1993 – 1994	Staff Scientist/Industrial Hygienist, Environmental Health & Engineering, Inc.
1989 – 1993	Industrial Hygiene Services and Training, through an independent training company and the New England Laborer's Union
1989 – 1993	Industrial Hygiene Technologist, Massachusetts Institute of Technology
1987 – 1989	Field Operations Supervisor, Hygenix, Inc.

EDUCATION

M.S. Industrial Hygiene, University of Massachusetts, Lowell, MA, 1993

B.S. Biology, Fairfield University, Fairfield, CT, 1987

TECHNICAL EXPERIENCE

Kevin Coghlan has over 30 years of progressive, broad-based experience in assessing, evaluating, characterizing, and developing solutions for demanding occupational/environmental challenges. He has personally managed and directed several hundred occupational/environmental investigations across a range of work environments including healthcare, research, residential, institutional, biotechnology, high technology, brown fields and industrial settings. Mr. Coghlan has been selected to investigate some of EH&E's most sensitive cases, often directing complex exposure assessment and exposure modeling projects with challenging risk/hazard communication and management aspects. Key project components included; characterizing potential hazard/health risks, measuring and modeling exposures, formulating risk/exposure control measures and communicating to a wide range of audiences regarding potential hazards and risks, e.g., hazard communication, [M]SDSs, labeling, etc.

The following represent a sample of Mr. Coghlan's project experience:

- Principal Investigator/Project Manager for environmental exposure assessment of PCBs released from building materials. Study included; quantifying airborne and surface concentrations of PCBs, characterizing and apportioning sources of PCBs in indoor media and conducting biological monitoring (e.g., blood sampling). The data were then consolidated and analyzed. The results of the study were communicated to the stakeholders that included administrators, faculty, staff, and the media. Follow-up work involved providing scientific assistance in a case-referent epidemiological study of cancer mortality at the site.

- Selected as a peer reviewer for EPA's *Laboratory Study of Polychlorinated Biphenyl (PCB) Contamination and Mitigation in Buildings Part 1. Emissions from Selected Primary Sources*, published by the National Risk Management Research Laboratory. In this assignment, I reviewed and commented the technical aspects of the work that characterized the emission rates and profiles of caulk and small capacitors that contain PCBs. The data from this work was used to inform models that characterize indoor air concentrations of PCBs.

- While serving as Director of Environmental Affairs for a large healthcare/research organization, Mr. Coghlan developed and implemented a wide range of chemical and biological safety programs to support 8,000^{+} employees. Programs included hazard communications, MSDS management, labeling, respiratory protection programs as well as special emphasis programs dealing with mold control for high risk patients, hazardous drugs/high potency compounds, formaldehyde safety, asbestos program management, indoor environmental control of VOCs and other indoor contaminants and a large-scale chemical management system for research operations.

- Served as project manager for the decommissioning of a large foundry involving potential exposures to lead, heavy metals, asbestos and polychlorinated biphenyls (PCBs). Work involved sample collection, data interpretation, specification of personal protective equipment, development and implementation of hazard communication programs and site safety plans.

- Project Manager and Project Director for environmental monitoring on a large-scale Brownfield development, including the formulation of health-based exposure levels and the execution of a perimeter monitoring program to assess airborne levels of lead, asbestos and dust during site development. Project involved extensive regular communications regarding potential hazards and data interpretation with the surrounding community and regulators.

- At the Massachusetts Institute of Technology, conducted all aspects of asbestos exposure control including; surveying buildings to identify the presences, type and extent of asbestos containing materials, conducting workplace exposure assessments, analyzing air and bulk samples for asbestos content, preparing abatement specifications for removal and demolition work, drafting reports and communications as well as conducting worker training.

- Project Manager and Principal Investigator for an electrical fire in a world-renowned research center. Role included providing technical consultation on root cause identification and providing advice and support for risk communication with the stakeholders. Risk management and communication aspects of the project were of paramount importance. Developed an innovative environmental risk assessment approach using source combustion markers and tracers to map contamination in the indoor environment that provided the framework to communicate the environmental risks to a committee of Principal Investigators.

- Scientific advisor/team member for occupational exposure simulation studies to support retrospective exposure investigations.

- Expert witness/consulting expert service experience for environmental and workplace health and safety cases, including deposition and trial testimony experience. Testimony has never been excluded.

- Overall, Mr. Coghlan has extensive experience on projects that required the identification and remediation of numerous environmental/occupational hazards including; chlorinated hydrocarbons, asbestos, lead, heavy metals, semi-volatile organic compounds, volatile organic compounds, pesticides, PCBs, fibers, microbiologicals, formaldehyde and noise.

- Project oversight for decommissioning and redevelopment of a linear accelerator and monitoring programs related to various manufactured gas plant sites, including plan design and setting appropriate public heal standards.

- Project oversight for the development of a lead exposure control program for painters, including exposure assessment and exposure control.

MANAGEMENT EXPERIENCE

While serving in these management positions below, Mr. Coghlan continued to have major technical responsibilities in his role of Principal Scientist at EH&E. In this role he provided technical oversight on projects involving potential exposures to many types of chemical, physical or biological agents, e.g., PCBs, formaldehyde, asbestos, mold, lead, heavy metals, VOCs. As a Principal Scientist he continues to have an overall scientific/technical role in projects across EH&E that included activities from hazard identification and exposure assessment through installation and evaluation of hazard controls as well as hazard communications and risk management.

As Chief Operating Officer, Mr. Coghlan has executive responsibility for corporate operational functions, including strategic planning, quality control and assurance, contract authorization and negotiation, human resource management, information technology and corporate development and planning.

In his role as Director for the EH&S Compliance and Strategic Support he managed 23 full-time environmental health and engineering professionals performing a wide range of technical support services including industrial hygiene, safety, and environmental affairs.

PROFESSIONAL AFFILIATIONS

Diplomat of the American Board of Industrial Hygiene
Member of the American Industrial Hygiene Association
Boston University Metropolitan College, Lecturer for Environmental Health and Safety

PROFESSIONAL CERTIFICATION

Certified Industrial Hygienist in Comprehensive Practice (Certification #6125)

PROFESSIONAL TRAINING

Advanced training in Industrial Hygiene Statistics, Sampling Strategies, Bayesian Decision Analysis and Censored Data Analysis
Management, Communications, and Technical short courses, Harvard School of Public Health and the American Industrial Hygiene Association
Executive Management Coursework, MIT Sloan School of Management
Executive Coursework in Negotiations, Program on Negotiations, Harvard Law School
NIOSH 582 course: Sampling and Evaluating Airborne Asbestos Dust
EPA approved training program for asbestos inspector, management planner, designer and monitor
McCrone Institute, training in polarized light microscopy (PLM) techniques

HONORS

Outstanding Graduate Student Award, University of Massachusetts, Lowell; Department of Work Environment, 1993.

SELECTED PRESENTATIONS AND PUBLICATIONS

Coghlan KM. 2013. PCB Emissions from Building Sealants and Factors that Influence Exposure and Risk to Building Occupants; PCBs in Construction Round Table. *American Industrial Hygiene Conference & Exhibition.* Montreal, Canada. May 18-23, 2013.

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PEER REVIEWIER

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APPENDIX D

STATEMENT OF COMPENSATION

I am a salaried employee of Environmental Health and Engineering, Inc., located in Newton, Massachusetts. My company is compensated $340 per hour for my time. My compensation is not contingent on the outcome of this or any other legal case on which I consult.

APPENDIX E

TRIAL OR DEPOSITION TESTIMONY OF KEVIN M. COGHLAN FOR LAST FOUR YEARS

Confidential Arbitration for Defendant, PCB Fate and Transport Expert, London, England. March, 2017.

APPENDIX F

CASE DOCUMENTS

CASE DOCUMENTS

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